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# ELECTRIC WIRING

# ELECTRIC WIRING

FOR THE USE OF

ARCHITECTS, UNDERWRITERS, AND THE
OWNERS OF BUILDINGS

BY

RUSSELL ROBB

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# PREFACE.

THERE has been no attempt to set forth here all the principles of electricity, nor to make this book take the place of engineers. There is a small amount of electrical knowledge that is helpful to the three classes addressed, and this has been presented in the way that seemed simplest and in the order that seemed most natural. Much space has been given to the National Code of Rules for Electric Wiring because these rules furnish the standard in America for safe electrical construction. As a help to thorough comprehension it has been thought well to give the reason for each rule and to explain, with both text and illustrations, the meaning of all technical terms and phrases that are used. The contents of the book have appeared during the last two years in a series of articles in "The American Architect and Building News."

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# ELECTRIC WIRING.

## CHAPTER I.

### INTRODUCTION.—INSULATION.—ANALOGIES.—THE ELECTRICAL UNITS.

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ONE hears very often that this is an age of specialists. We are told time and again that all our thought and endeavour must be given to one branch of work, if there is to be any advancement. Yet it seems quite as true that there has never been a time when one must have so broad a knowledge. The development on all lines has been so great, and, in all branches of engineering, at least, these lines have become so interwoven, that one must greatly broaden interests and knowledge if the most is to be made of the special work. We may know only one thing, but we have to *know about* a great many.

Electrical engineering and architecture are certainly distinct, yet electrical matters are every year brought more to the architect's attention. Electric-lighting, the increasing application of the motor to elevators, pumps, ventilating-fans, etc., and the innumerable bells, burglar-alarms, gas-lighting arrangements and similar conveniences, have a rather important place in the equipment of buildings, and the electrical item is one of too much consequence to be turned over *carte blanche* to contractors or arranged for without due consideration. It is becoming important that the architect should know a little about the nature of electricity, the uses it can be put to, and what safe, economical, and durable electrical work is. Electrical power can be so cheaply and so conveniently brought into buildings of any size that there is no limit to its possible use. Already it is being seriously considered in connection with heating and cooking, and if the hopes of inventors are realized, the need for providing for the use of electricity and for looking most carefully into all electrical arrangements will grow into a necessity.

There seems to be an inclination to look upon all electrical matters as quite out of the range of ordinary work and interests, perhaps as something too mysterious to comprehend without that thorough study for which there is not time. But every architect knows something about plumbing, steam-heating, and gas, and the necessary knowledge about electrical matters is scarcely more occult. It would all be simpler if we but had an "electrical sense," so that we might be impressed directly by electrical phenomena. As it is, much occurs without giving any evidence that can be appreciated by our five senses. When a wire is tapped here and there and a part of the electrical energy is translated into some other form that we recognize, such as light or heat, it seems an unreasonable and miraculous occurrence, for with our limited perceptions we cannot follow from cause to effect. When a little familiarity with the phenomena is acquired we are apt to forget the miraculous part just as we do on seeing an object drop toward the earth. We become content simply to give a name to the force. It seems to bring electricity nearer when it is thought how little we should know about heat for instance, if there were no sense of feeling. A good deal could be learned about it in a slow way, but its actions would be very mysterious. We should, perhaps, see a piece of wood suddenly blaze up, and a kettle of water a foot above it begin to dance about and boil, and yet we might pass our hands between the fire and the kettle with no appreciation of anything happening there. Steam might be carried from a closed kettle through a pipe to a small engine. The pipe might be of glass and nothing would be seen, so if we had no sense of feeling we should see only a piece of wood blazing, and a machine, with no apparent connection, doing work. This would surely not be less mysterious than the working of an electric motor.

Electricity is not an erratic, uncertain thing. The laws that govern electrical forces are well known, the forces can be controlled without great trouble, they can be measured with the greatest accuracy, and the way they will act under given conditions can be definitely foretold. Whatever electricity really is and whatever may ultimately be found true with regard to its nature, it is known that it acts very much as if it were a fluid, and all the actions of water flowing in a pipe are closely analogous to electricity "flowing" in a wire. We cannot go very far wrong when we look upon it in this way, and as water flowing in a pipe is such a familiar phenomenon, a great number of useful analogies are at hand, and an easy way is open to understand many of the actions of electric currents.

In the earlier days of electricity, when trained workmen were scarce and the needs were not so well understood, and when, it might be added, the underwriters were not so hard upon the heels of the contractors, there was a great deal of exceedingly poor and slipshod work done. Electricity was fast getting the reputation of being most untrustworthy, if not actually dangerous. This idea is being dispelled under the improved conditions, and although much bad work is still done and most of the wiring is far from perfect, still it has been proved that even in the most difficult places, electricity can be employed with the greatest surety of action and freedom from danger. The underwriters have done much to bring about the improved state of affairs, for surety of action and freedom from fire causation are very closely related.

Faulty circuits are not always easily discovered, for there is often no sensible evidence of defects until they are looked for with great painstaking or until they suddenly become worse and give sensational notice of fault. It is consequently of great importance that the work be done thoroughly at the start. It is not a difficult matter to confine electricity to its proper conductor, but to do so it is absolutely necessary that every care be taken with the insulation. With all metals such good conductors, and with brickwork, plaster, and damp wood conductors in some degree, there is great liability that the current will go astray.

It is common to compare a current of water with a current of electricity, but there is one striking difference. Water flows freely in space, and to conduct it we surround a certain amount of space with metal — we use a pipe. The metal is the insulator through which the water cannot pass unless the metal be punctured. Electricity does not "flow" freely in space, but does through metals. Space is the impassable and the metal is the "hole." When wires are strung it may be looked upon as punching holes for the electricity to flow in, and if these "holes" are not surrounded by some non-conductor it is of course impossible to keep the electricity in the path intended for it. Pipes are strengthened and joints are looked after with regard to the pressure upon them. Electrical insulation should also be looked after with regard to the pressure which it is to withstand, for there is an electro-motive force that is analogous to water-pressure. In insulating wires the difficulty comes from the fact that electric insulators can be either punctured or permeated by conductors. Sometimes the insulators themselves become conductors through the action of heat or other deteriorating agents, and it is thus necessary to provide, in one way or another, against a number of accidents. If a nail pierce the insulation, if dampness permeate it, or if it become charred by heat, there may be leakage. It is as if a water-system were tapped by small pipes through which the water constantly leaked away, only the waste with electricity is far more subtle and attracts no attention unless, because of the leak, there is a lack of power in the circuit. And it is by no means the waste only that makes leaks undesirable. There is often a very small margin between a small leak and a great one, and if it is large it carries off practically all of the electricity, leaving nothing for useful purposes, and in doing so is very apt to cause a part of the circuit to heat to a dangerously high temperature. But even in damp cellars, tunnels, and mines, electric circuits are in successful operation. If a few principles are kept in mind and a few rules carefully followed leaks will be impossible under normal conditions.

The strangeness of electrical terms is, perhaps, largely accountable for the lack of knowledge about electrical matters. It is discouraging to meet at the start with "volts," "ampères," "ohms," "watts," and other names and expressions as mysterious as the cabalistic signs on a physician's prescription. But it is only another illustration for Carlyle's "Philosophy of Clothes." Electricity is not the only subject that is looked upon with increased respect and awe because of the peculiar names given to ideas concerning it.

This clothing of the ideas no doubt obscures many simple facts and fails to suggest their semblance to ideas that are familiar, but in the end it is an aid to clearness to have the terms distinctive. When once there is clear conception of the fundamental ideas, the electrical nomenclature is found simple and direct, and it is an advantage to have specific terms that will not suggest too readily, foreign ideas not analogous in all particulars. It is, perhaps, this very directness, the absence of all roundabout terms, that makes most electrical talk sound highly technical. It is encouraging to the uninformed to meet in explanations with "pounds," "feet," and other common quantities, because they are familiar, and the most abstruse talk in some way seems to gain clearness when this much is understood. It is, however, largely a question of familiarity, and it is doubtful that our knowledge of the ultimate meaning of pounds and feet is much clearer than our knowledge of volts and ampères.

Analogies are sometimes confusing because they are taken too literally, and the attempt to reconcile the analogous ideas in all particulars will sometimes cause more confusion than if a more abstract conception were attempted at the start. Thus, although it is often helpful, it is not necessary to compare electrical forces and quantities with those that seem to have a more material existence. Instead of comparing them with pressure of steam, currents of water, or resistance of friction, we may compare them, for instance, with the "pressure of public opinion," "currents of feeling," "resistance to changes." These expressions have a definite meaning to us even though the ideas themselves do not appeal to the five material senses. If there were a way to measure "the pressure of public opinion," we should probably do so, fix upon a unit and give a name to it; but when we cannot do this and yet can measure "electrical pressure," it would seem as if the latter should be not less clearly recognized.

We have these abstract ideas of pressure, resistance, and current, and if they are kept in mind while the names are looked upon as figures of speech rather than as literal definitions, the ideas are of great usefulness.

There is what is termed "electrical pressure" or electro-motive force. It is a definite force and can be measured, although it does not show its effect in quite the same way that water-pressure or steam-pressure does. We do not see it push masses of substance before it, but the abstract idea of pressure can be applied to it just as we apply the idea to "pressure of public opinion." It causes certain actions in an electric circuit. When the force is great the action is great, when it is small the action is accordingly small. It agrees with our idea of pressure, and by thinking of it as such, a clear conception of its nature is helped. Resistance, current, and other electrical quantities may be looked at in the same way. It is not necessary to assume that there is an actual flow of something material. It is not known that anything material actually passes through a wire, but it is known that there is a progressive effect along it as if there were a "current" of something, and that this effect is produced by the electro-motive force which acts "like a pressure."

When once it became known that definite electrical forces and quantities exist and give rise to certain effects, and when these had been named, it remained of course to decide upon units, so that these forces and quantities might be measured and compared. It is hardly necessary to discuss here how or why the different units were made what they are, nor to mention more than the three or four most commonly used. As is generally known, the units have been given the names of the physicists who have done most for electrical science. Thus the unit of electro-motive force or electrical pressure, corresponding to "pounds per square inch" in hydraulics, is called the "volt," and the electro-motive force is often spoken of as the "voltage." The unit of current, corresponding to "gallons per minute" in hydraulics, is called the "ampère." There is no unit of resistance in hydraulics: it is recognized by its effect upon the pressure and is spoken of as being equivalent to so much loss of "head" or "pounds per square inch" pressure. In electrics the resistance may also be recognized by its effect upon the pressure, but it is readily measured as a resistance simply, and is expressed in terms of a unit called the "ohm."

These quantities come to have a definite meaning as they become familiar through use. One mentally forms a rough idea of the number of units of electro-motive force, current, and resistance in an electric circuit, from the actions that take place, from the visible manifestations of the electrical energy. By continued experience one gradually gets an idea of the relative resistance of conductors of different sizes and materials; an idea is formed of the amount of current that is necessary to heat them or to cause the different magnetic effects, and of the amount of electro-motive force necessary to force different currents through a certain length of conductor.

There is nothing in an object to tell of its hardness or of its softness except its similarity in various ways to other objects that we have felt; there is nothing to show the temperature of a body except the effects that are seen when the heat energy is changed to other forms; but continued experience teaches us to appreciate all these slight changes and small actions. Electrical forces and quantities become familiar and seem real by the same process, and with experience one intuitively forms rough judgments just as one does of weight or temperature.

It will, perhaps, help to form an idea of a few of the electrical quantities, if their magnitudes in some common instances are mentioned:

The electro-motive force of a voltaic cell, such as is used in batteries for telegraph and telephone work or for ringing electric bells, is from 1 to 2 volts.

The pressure at the terminals of an incandescent lamp is usually either 50 or 110 volts.

The pressure used in electric-railway work is nearly always 500 volts.

The current through an incandescent lamp when made for a pressure of 50 volts is about 1 ampère;

when made for a pressure of 110 volts the current is about ½ ampère.

The current through an arc lamp when it is of 2000 nominal candle-power, is about 10 ampères.

The resistance of a copper wire .01 inch in diameter and 10 feet long is almost exactly 1 ohm.

The resistance of a German silver wire .01 inch in diameter and 1000 feet long is about 1500 ohms.

A copper wire .5 inch in diameter and a mile long has a resistance of about .2 ohm. The same wire 10 miles long would have a resistance of 2 ohms, the resistance being proportional to the length. If the same wire were one-half the diameter it would have four times the resistance, the resistance being inversely proportional to the sectional area and consequently inversely proportional to the square of the diameter.

## CHAPTER II.

### THE PROPORTIONING OF WIRES.—THE HEATING EFFECT OF THE CURRENT.—LOSS OF FORCE.—OHM'S LAW.—WIRE CALCULATION.

A MATTER of great importance in electrical work, with regard to both safety and satisfactory service, is the correct proportioning of wires to the currents they have to carry. Conductors always offer a resistance to the passage of the current, and this not only causes heating of the wire and waste of energy, but it diminishes the pressure at the lamp, motor, or other device operated.

A current of electricity, however small, will heat in some degree a wire of any size, and if the current be large and the wire small this heat may become of great intensity. The effect is not different from that in any case where resistance is overcome by force. When a nail is driven into lead it is very plain that the energy is transformed into heat. Meteors falling through the atmosphere are heated to incandescence, and even when water is forced through a pipe, a part of the energy is transformed into heat because of the resistance of friction. We may not know exactly how a current of electricity sets the molecules of a conductor in motion and thus produces heat, but we do know that it requires a certain force to make a current flow in a wire, and that if we make the wire smaller it takes more force to send the same current through it. We know, too, that if the heat generated is measured it is found to be equal to the energy expended. By making the wire smaller, the resistance is increased and more force must be applied so that this resistance may be overcome.

If a pump is to deliver 100 gallons of water per minute through a pipe, it will take a certain amount of force even though the pipe be a foot in diameter, but if it be reduced to one-tenth the size, it will take enormously more force and the additional amount will all be used simply in overcoming friction — in heating the pipe and water. In this case the heat is carried away so fast by the water itself that it is of course only the waste of power that is serious. In forcing electric currents through wires, however, not only is energy wasted, but the heat is left in the wire to dissipate as best it can. The wire goes on heating until the generation of heat is balanced by the dissipation, and if the current be much too large the wire, in the meantime, may become of such a temperature that it will set fire to inflammable material near it. It is not the total amount of heat generated that determines the temperature, for the wire may be long, and the heat is then distributed, or it may take so long to generate the heat that it is dissipated as fast as it is produced. The temperature is determined by the rate of generation per foot of wire. Thus though the whole of the resistance in an electric circuit is what determines the total heat generated by a given current, it is the amount of resistance per foot that, with a given current, determines the temperature to which the wire will be raised. On the other hand, since all heat generated means lost power, it is the total heat and not the temperature that affects the available force at the lamp or motor.

It is partly because of these facts, that wires of inadequate size are so often used. The total resistance may not be sufficient to absorb an appreciable part of the force and so affect the lamps or motor, but the resistance for a given length of wire may be sufficient to cause more heat than can be dissipated by that length without great rise in temperature.

The boards of fire underwriters have, accordingly, determined upon proper "carrying capacities" for the different sizes of copper wire, and wiremen generally now follow the tables provided. As inflammable material is often brought near electric wires and as excessive heat destroys the insulating properties of the covering, but little rise in temperature is allowed.

The compliance with the underwriters' rules in this regard has done a great deal to make incandescent-lighting service satisfactory. Whatever energy is lost in heating the wire is, of course, unavailable for heating the filament in the lamp. The effect of the rules is to limit the loss, or heat, per foot. There might be a very small loss per foot and yet a serious total loss, but for short distances the minimum sizes of wires allowed by the underwriters are often larger than would be necessary if consideration were given only to the effect upon the lights. In places where a small number of lights are used and where, ordinarily, guess-work would be resorted to, the rules thus do much toward securing good service.

As soon as the wiremen get away from compulsion, however, they are apt to make the wires too small for good results. Since every foot of wire has its definite amount of resistance depending upon its size, a definite amount of force depending upon the volume of current is spent in overcoming the resistance in each foot. The amount of force or pressure in incandescent-lighting is ordinarily kept constant, and if all the lights in a building are to burn with equal brilliancy, the loss of force in the wires leading from the mains to the lamps must be made negligible. To this end the wire must be chosen with regard to both the distance and the number of lamps, for it is the distance that determines the total resistance, and the number of lamps or "load" that determines the volume of current.

The analogy between the distribution of electrical energy and the distribution of water or gas is useful here. In the holiday season, when the volume of gas drawn off is very great, the lights are often noticeably poor. The pipes offer so much resistance that the usual pressure at the gas-works is not sufficient to force along the great volume of gas and still give the ordinary pressure in the buildings. The same effect is seen in long lengths of water-pipe. If water be drawn from cocks near the supply, much less will come from a cock farther off, although the pressure at the pump may remain the same. The pressure at the gas-jet or water-cock cannot be kept up, and in the same way the electrical pressure falls before it reaches the lamp terminals, if too small wires are used. Each incandescent lamp requires its own small but definite amount of current. Turning on the current is like turning on water or gas, but the filament of the lamp offers so much resistance that the force at the terminals can send only a very fine stream, so to speak, through it, just as a very small pipe will allow but little water to pass.

The lamp itself is a good illustration of the heating effect of the current. There is a great resistance per foot in the filament. Even the small current passing through generates heat so fast that it can be dissipated at an equal rate only when the whole is incandescent. The construction of the lamp gives a conductor of considerable resistance in small space, and it is designed to give the filament "long life," but any conductor will be heated to incandescence provided sufficient current be passed through it.

A lamp is made to be used at a certain electrical pressure, and it is only at this pressure that the proper amount of current will go through it and thus cause the proper amount of light. It is for this reason that it is so important to calculate the sizes of the wires and thus give every lamp as nearly as possible the same pressure. Every branch of a line requires a separate calculation, for there are different volumes of current in each branch, and the lamps are at different distances. It is at this point that rule-of-thumb methods fail, and some degree of engineering ability becomes necessary to prevent excessive loss in the wires and on the other hand to prevent unnecessary expenditure for copper in the conductors. In buildings improperly wired, it will frequently be noticed that lamps in one part will be much brighter than those in other parts, or it will be found that when all lamps are turned on the light is poor, and that it improves when some of the lamps are switched off. In these cases it will almost invariably be found that some of the wires, usually the longer ones, are too small.

There is no excuse for this sort of work except the saving it effects in the cost of material. It is not a matter of judgment nor of experience, but simply of calculation. It is known how much current each lamp requires, and exactly how much the pressure will be lessened when the necessary current is forced over a given length of wire of a certain size. With no other force that we use can results be so easily and so exactly predicted.

Of course, with wires of reasonable size there must always be some difference in the lighting effects of any two lamps, but it is not a difficult matter to make it so small that the eye cannot detect it. It is now ordinarily specified that the electrical pressure at any two lamps in a building shall not differ by more than two per cent under any conditions of use. This difference is within reasonable limits, and is sufficiently small to prevent noticeable change in lights when others are turned on or off. Not infrequently it is required that the pressure at no two lamps shall differ by more than one per cent.

The prediction of results in electric circuits and the laying out of systems of distribution are greatly facilitated by the simplicity of the law that controls the relation between current, pressure, and resistance. To quote an expression of this law: it "is a special statement of the results of ordinary observation and it may be generalized thus: a result is equal to the effort put forth, divided by the opposing resistance or opposition." Thus the result is twice as great if there be half the opposition or only half as great if there be one-half the effort. This general law is easily applied to electric circuits because of the independence of the factors. The law applies to water flowing in pipes, but upon attempting calculations, one at once sees the complicated nature of the resistance. This depends not only upon the size of pipe, but upon the number and sharpness of the bends, and even upon the velocity of the water itself, so that what promised to be a simple determination, becomes an intricate web of dependent factors. With electricity, however, except under special conditions, we have to deal with only the three factors, effort, resistance, and result, in their simplest form.

This one law, called in electrics "Ohm's law," is so widely applicable in engineering work that its expression in the form of an equation is looked upon as almost symbolic of electrical engineering. The electromotive force is the effort and is usually represented by $E$. The resistance is the opposition to this effort and is represented by $R$. The current is the result and is represented by $C$. Thus the general law, "a result is equal to the effort put forth, divided by the opposing resistance or opposition," when applied to electric circuits takes the simple form $\left(C = \frac{E}{R}\right)$. It is of course necessary to know only two of these quantities to determine the third.

Suppose there is to be a current of ten ampères in a circuit that is known to have a resistance of two ohms. The substitution in the formula shows at once that the electro-motive force or pressure necessary to give this result is twenty volts $\left(10 = \frac{E}{2}\right)$. Or, there may be an electro-motive force of ten volts, and the circuit may be composed of a coil of copper wire .162 inch in diameter and 2000 feet long. Copper wire of this size and length is known to have a resistance of .8 ohm so that with ten volts pressure and with the .8 ohm resistance there will be a current of $12\frac{1}{2}$ ampères $\left(C = \frac{10}{.8}\right)$. With the aid of this law, circuits and parts of circuits may be examined, and losses or results determined with exactness. In the illustrations given, the complete circuits were taken, but the formula is applicable also to any part of a circuit, if the resistance of this part and only the portion of the electro-motive force used in overcoming this resistance, be substituted in the formula.

The "drop" in pressure may be shown graphically, as in Figure 1, which illustrates the loss of pressure between wires leading to incandescent lamps.

Suppose the dynamo or other source of electricity is at *A*, and that the pressure at that point is 110 volts.

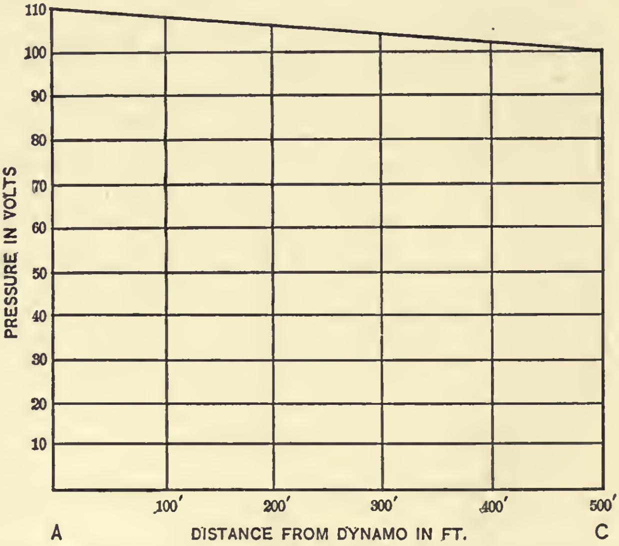

Fig. 1.—Illustration of the Loss of Pressure in Electric Circuits.

Suppose that at *C*, 500 feet away, there is a cluster of 20 lamps, each requiring one-half ampère to make it burn at the proper candle-power. Then there should be a total of 10 ampères flowing in the circuit. If the lamps were at *A*, attached directly to the leads from the dynamo, they would of course have the benefit of the full pressure, and the whole resistance of the outside circuit would then be only the resistance of the lamps. But if they are 500 feet away from the dynamo, long wires will have to be used; these will have a certain amount of resistance, and a certain amount of electro-motive force will have to be used up in overcoming this. Let it be assumed that No. 10 copper wire is used to connect the lamps to the dynamo. Five hundred feet of this wire will have a resistance of almost exactly one-half ohm. The wire runs to the lamps and back again, however, so the resistance of the wire part of the circuit will be one ohm. Thus it will be necessary to force 10 ampères through this one ohm resistance and also through the lamps. The amount of electro-motive force that it will take to force 10 ampères through one ohm resistance can be seen at once by substituting in the formula;

$$C = \frac{E}{R}, \ 10 = \frac{E}{1}, \ E = 10 \text{ volts.}$$

Ten volts will be used up in the wires, and since there is a pressure at the dynamo of but 110 volts there will remain only 100 volts for forcing the current through the lamps to produce light. By letting $A$–$C$ in the figure represent the distance between the lamps and the dynamo, and the perpendicular lines the amount of pressure at different points, it can be seen how the pressure falls along the line; at 100 feet, for instance, the pressure has fallen two volts, which is the amount required to force the ten ampères through the first 100 feet of the wires.

If the lamps are made to burn properly at about 110 volts, the wire must be about 10 times as large in sectional area or else the dynamo must be made to give 120 volts, so that there will still be 110 volts left at the lamps after the resistance of the line has caused a loss of 10. But the effect of raising the pressure at the dynamo can be realized by imagining all but one of the lamps turned off. There will now be only one-half ampère flowing and only one-half volt will be used up in forcing this against the resistance of the wire $\left(\frac{1}{2}=\frac{E}{1}\right)$. This will leave 119.5 volts at the lamp, which is such an excess over the voltage for which it was made, that it would soon be destroyed. If, on the other hand, the wire is made ten times the sectional area, it will have only one-tenth the resistance, or .1 ohm. When all the lamps are on, the pressure lost in the wire will be one volt $\left(10=\frac{E}{.1}\right)$, and if the pressure at the dynamo is 110 volts, there will be 109 volts left for useful effect at the lamps. When one lamp is on, the pressure lost in the wire will be .05 volt $\left(\frac{1}{2}=\frac{E}{.1}\right)$, and there will be 109.95 volts at the lamp. Thus, if the resistance of the wires leading to the lamps be kept as low as .1 ohm, either one lamp or twenty may be turned on and there will not be a difference in the pressure of more than .95 volt, an amount so small that no change in the strength of the light could be detected by the eye. Even at the dynamo or at any intermediate point, a lamp would have practically the same pressure.

It can be seen from the examination of this case how necessary it is for satisfactory service, that there be equality of pressure at all lamps at all times. The calculations are often complicated by the number of branches and the positions of the lamps, and experience assists one to see quickly what will probably be the best arrangement ; but the loss may always be found by an application of Ohm's law, and even with experience one must in the end rely upon this to ascertain the exact sizes of wire.

The first cost of a plant and the cost of maintenance may in several ways be affected by the proportions of the wires and the method of laying out the system. The wires may be so small that a large part of the energy delivered by the dynamo is wasted in worse than useless heat, as has been shown ; but the conductors may be of sufficient size to prevent excessive loss and to keep the pressure constant at the lamps, and yet be arranged so that a much larger amount of copper is used than is necessary. Since the length of the wire, as well as the sectional area, makes a difference in the resistance, there is need of judgment in placing the main wires, in choosing "centres of distribution," and in dividing the circuit into the different branches. In a large building there is opportunity for a good grade of engineering skill and to have this work done by any one except those who have studied this branch of engineering and who are familiar with the requirements, is sure to result in loss.

There should always be equality of pressure at the lamps for another reason that is not commonly considered. All lamps are not made of the same "efficiency." That is, for a light of sixteen candle-power, some will require more energy than others — more coal will be burned under the boilers. The most efficient lamps require a practically constant pressure, of the amount for which they are designed. If the pressure rises more than a very little above this, the lamps have a "short life," and it is only in plants where the regulation at the dynamo is of the best, and where the wiring is calculated for a very small loss, that they can be used. If the wires are so small that turning off a number of the lamps causes the pressure at those remaining to increase by several volts, the more efficient lamps cannot be used on account of the expense of renewals, and it is necessary to use those that will not be too much affected by the variation. Such lamps can be had and are widely used, because there has been much poor engineering and the breakage must be kept small. Their use is, however, made necessary only by the variation of the pressure, and they are a constant expense because of the greater cost to operate them.

## CHAPTER III.

### SYSTEMS OF DISTRIBUTION. — THE SERIES SYSTEM. — THE MULTIPLE SYSTEM. — HYDRAULIC ANALOGUES. — THE THREE-WIRE SYSTEM.

LAMPS, or other electrical devices, may be connected in a number of different ways to form a distributing system, but considerations of safety, convenience, or practicability have narrowed the methods down until there are but two in general use. These are the plain "series" and "multiple" systems. Arc lamps, and incandescent lamps for street-lighting, are usually operated "in series," while incandescent lamps for general use, motors, and other devices, are almost always operated "in multiple."

When lamps are operated in series, the same current passes through each, and all lamps in the circuit are interdependent. If the circuit be broken in any place, all the lamps go out. With this system the current is kept constant, and if more lamps are added, the pressure at the dynamo must be increased to overcome the added resistance. To cut out any of the lamps, it is necessary first to make a by-path round the lamp to preserve the continuity of the circuit, and then the connection to the lamp may be broken. But it is also necessary either to replace the lamp by an equivalent resistance or else to lower the pressure at the dynamo, for otherwise the strength of the current would be increased in proportion to the decrease in the resistance of the circuit. Figure 2 represents an electric circuit in which the lamps are connected in series.

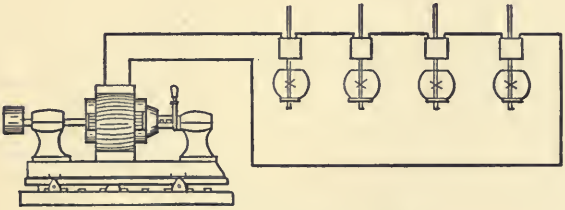

**Fig. 2.—Arc Lamps in Series.**

The principle of this series system can perhaps be brought out more plainly by showing its analogy to a system of water-wheels operated by one stream of water. In Figure 3 are shown three water-wheels in series, or, as it is sometimes expressed in electrical parlance, "in tandem" or "in cascade." The pump, which is analogous to the dynamo, creates a pressure, raises the water to a height, and gives it a definite "head." This pressure or head corresponds to the voltage or pressure in the electrical circuit. The water passes through a pipe to the wheels, in a stream corresponding to the electric current, and operates the water-wheels which here take the place of lamps. At each wheel there is a definite resistance to the flow of the water, and a part of the energy is transformed into the work done by the wheel. The water falls to the next wheel where it has a diminished head, but the same in proportion to the number of wheels it has yet to operate. If another wheel were added, the pump would have to be run so that it would give proportionately greater pressure or head, but the current or flow of water would remain the same, for the resistance would be proportionately increased.

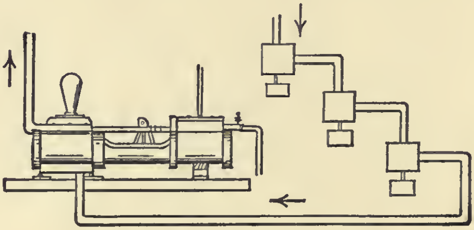

Fig. 3. — Water-wheels in Series.

It will be noticed that the working of the wheels is influenced only by the pressure or head that exists between the point where it leaves one wheel and the point where it leaves the next. It makes no difference how many or how few are in the series, provided only that the total pressure is sufficient to keep this pressure for each wheel the same. It is the same in the electrical series; the current is kept constant, and the pressure necessary is the pressure needed for each device, multiplied by the number of devices. Thus, a "2000 candle-power" arc lamp requires, approximately, 50 volts pressure. If there are 50 lamps in series, the total pressure at the dynamo is 2500 volts; if there are 10 lamps in series, the total pressure is 500 volts. The current in the circuit would be the same in both cases, about 10 ampères.

It will be seen, too, in the water-wheel illustration, that if one wheel be shut off by closing a valve in the pipe above it, all the wheels will stop, for the continuity of the circuit will then be broken. If one wished to stop one of the water-wheels, it would be necessary first to "short-circuit" one of them by opening a passage round it. The water running through the regular passage to the wheel could then be shut off entirely, and the current or flow would continue through the by-passage. This passage round the wheel could be made to offer exactly the same resistance that the wheel did, and in that case the pump could keep on developing the same pressure as before, and the other wheels would all continue to work uninterruptedly. If, however, the by-passage offered little or no resistance, the pump would, of course, have to be run so that it would not develop so much pressure, for otherwise the current would be greater through all the wheels, and might be more than they were made to withstand.

Water-wheels operated as shown in Figure 3, would all be transforming the energy due to the current of water into other forms. They would be doing work and "the rate of work" could be measured by multiplying the pressure, or head, by the flow of water, or gallons per minute. From this, the foot-pounds per minute, or horse-power, could be readily determined. And it is so with the electric circuit. There is work done at the lamps, where the electrical energy is transformed into the energy of heat and light, and this "rate of work" can be measured by multiplying the pressure, or volts, by the current, or ampères. One volt multiplied by one ampère gives one *watt*, the unit of electrical "rate of work." Seven hundred and forty-six watts make one horse-power, and there is here the direct connection between electrical energy and the more familiar mechanical energy.

When an electric circuit is broken, energy is no longer being expended, for although the electrical pressure may be kept constant, the current, the other factor determining the amount of energy, has become zero. The hydraulic circuit used for illustration is not, of course, completely analogous to an electrical circuit, but it can be seen with this, too, that if a valve were closed just above the pump, the pressure might still be there, the steam might be in readiness pressing against the piston of the pump, but there would be no work done until the valve should be opened.

In the arc-light circuit, it is the number of lamps that determines the horse-power necessary to drive the dynamo. Each lamp is converting electrical energy into light and heat, which are given out to surrounding substances. The carbon rods are made to be a part of the circuit, and the mechanism of the lamp brings them together for the circuit to be formed through them. When the current is forced through the high resistance at the place of the contact, the carbon points become heated and at the same time the mechanism causes them to be slowly drawn apart. The current follows across the intervening space, because the heated air and the hot vapours from the carbons are conductors to some extent. The resistance for such a short distance is, however, so great, that an intense heat is produced and the carbon points and detached particles are raised to a high degree of incandescence. This incandescence represents the expenditure of a definite amount of energy; of a certain amount of coal burned under the boilers. If there is a current of 10 ampères through the lamp and a difference of pressure of 45 volts between the point where the current enters the lamp and where it leaves it, then 450 watts, or about .6 horse-power, is a measure of the rate at which work is being done at the lamp.

The series system of lighting offers many advantages when arc lamps are used. With these, a high potential circuit is not seriously objectionable, and when the pressure at the dynamo may be 2500 or 3000 volts, a comparatively small wire may be used to transmit the energy required for the 50 or 60 lamps in a circuit. For example, 5 miles of No. 6 copper wire has a resistance of about $10\frac{1}{2}$ ohms. If this wire is carrying an arc-circuit current of 10 ampères, there is required 105 volts ($E = CR = 10 \times 10\frac{1}{2} = 105$) pressure to force the current through the resistance of the wire alone. This means that the rate of expenditure of energy, or rate of work, in the wire is 1050 watts ($\text{watts} = EC = 105 \times 10 = 1050$) or about 1.4 horse-power ($\text{horse-power} = \frac{\text{watts}}{746} = \frac{1050}{746} = 1.4$). This, however, would be only 4.2% of the total energy of the circuit if the pressure were 2500 volts at the dynamo. But suppose the total pressure at the dynamo to be 105 volts and the current forced through the circuit the same as before, 10 ampères. The loss in wasteful heating of the wire would be exactly the same, for it depends only upon the resistance and the current forced through this resistance. The total power of the circuit would be now, however, only 1050 watts $(105 \times 10 = 1050)$ so that the loss in the wire is 100%. The whole of the power would be spent simply in forcing the current through the resistance of the wire. There would be nothing at all left for useful work. If any lamps were put in circuit they could not have the full current. There would be an added resistance, and the current would immediately be less by an amount that would compensate for the work added.

In street-lighting, where the lamps are so widely distributed, there is another advantage in the series system. Since the lamps are connected in circuit one after the other, only one wire need be run to the lamp, and another away from it, to the next. Where the multiple system is used, it is necessary to run two wires in all places, and from these wires leads are taken off and connected to the lamp.

The series system is also satisfactory for incandescent lights in the streets, but it is unsuited for incandescent lamps for interior lighting. With lamps in all sorts of places as they are in a building, the voltage, or pressure, must be kept low, and each lamp must be independent of the others. If there are many lamps in series the pressure that is necessary is difficult to make safe; and the necessity, too, in the series system, of providing equivalent resistances or "shunting" devices for the lamps turned off, makes an awkward complication of apparatus. Incandescent lamps, and in general all devices except arc lamps, are consequently run on the multiple system, and even arc lamps for interior lighting are in many places being thus connected.

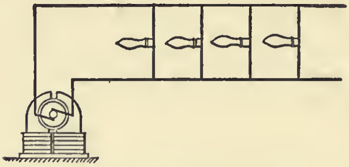

Fig. 4. — Incandescent Lamps in Multiple Circuit.

Devices connected in multiple are independent of one another, each receiving at its terminals the full pressure of the system, which always remains the same whether few or many of the lamps or other devices are being operated. It is here the current that changes, each lamp adding its one-half ampère, it may be, to the total load of the dynamo. The electrical circuit operated in this way is shown in Figure 4.

The hydraulic analogue may be represented as in Figure 5. Here, the pump keeps up between the two pipes, *A* and *B*, a constant pressure, and between the pipes are connected the water-wheels, *c*, *d*, and *e*. It will be seen that the wheels are quite independent of one another. *c* may be shut off by turning a stop-cock in the small pipe leading to it, without interfering at all with *d* and *e*. If the pressure between *A* and *B* is kept constant, the only effect caused by turning off one of the wheels is to diminish by one-third, the amount of water delivered by the pump.

The power expended in the whole circuit is here, as in the series system, the pressure multiplied by the current. In the series system the current remained always the same, while the pressure varied according to the number of devices operated, but here there is always the comparatively low pressure required by one device, and the current from the pump or dynamo varies according to the number of devices operated.

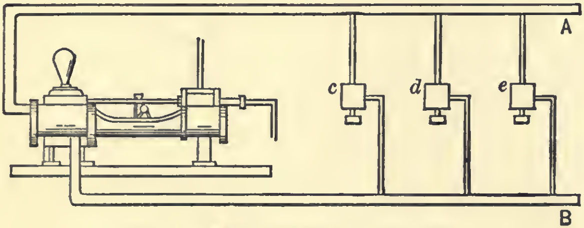

Fig. 5.—Water-wheels in Multiple.

The effect of a "short circuit" on an electric system may be appreciated by imagining a large pipe, one of very low resistance, connected directly between the two supply pipes, thus making a shunt, or by-passage, round the water-wheels. There would be nothing to limit the flow of water through this large pipe except the slight resistance to the passage of the water, and the ability of the pump to supply it. With an electric circuit on the "constant potential," or multiple system, there is an analogous effect when the wires are connected by a conductor of low resistance, or when they themselves come together. The dynamo is so constructed that it tends to keep the pressure constant. A tremendous current passes through the wires forming the short circuit, and if the dynamo is of sufficient size and there are no protective devices in circuit, the wires will heat until they actually melt.

It is commonly said that the electric current chooses the path of least resistance, but this needs a qualification to make it exact. With two paths more current will go through the path of low resistance than through the path of high resistance, but the total current will divide in exact inverse proportion. In Figure 5, a large pipe may be connected between *A* and *B*, and the flow of water in it will be proportional to the difference of pressure between *A* and *B*, and inversely proportional to the resistance of the connecting pipe. But the current through any other pipe between *A* and *B*, no matter how small, will also be proportional to the difference of pressure between its ends, and inversely proportional to its resistance, just as if the larger connecting pipe were not there. If the large pipe carries so much water that the pressure between *A* and *B* cannot be kept up by the pump, then of course the amount that will flow through any other pipe will be smaller than before the large pipe was connected. This, however, is because of the effect on the pressure and not because the water chooses the large pipe to the exclusion of the smaller.

The electrical multiple system may be elaborated by running from the mains, branches, and from the branches, taps, just as in a water or gas system branches or taps are taken from the main pipes. The dynamo is maintaining a pressure between the wires that lead from its terminals, and any branches that are taken from these wires are simply extensions of the mains, proportioned to the current they will have to carry. With a water or gas system, the free space outside, the air, may be looked upon as one of the pipes, and the devices used to keep up the pressure on the system are keeping up a pressure between the pipes and the free space. Electricity cannot flow in this space and it is thus necessary to provide the two wires.

Figure 6 shows an extended electrical multiple system. The mains, *AA*, will have to carry all the current passing through the lamps, or, if there are twenty lamps each taking $\frac{1}{2}$ ampère, the mains will have to carry 10 ampères. The branches, *BB*, carry only the current required by the lamps they feed, or, as the system is laid out in the figure, they will carry five ampères each. The taps, *CC*, will carry $2\frac{1}{2}$ ampères each. In this way the current may be distributed throughout a building, branches being led to various points and the taps taken off as lamps are required.

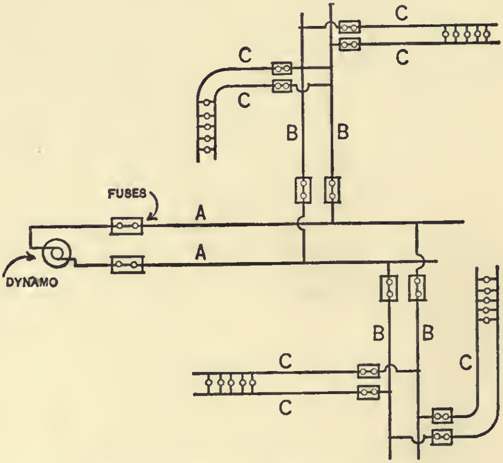

**Fig. 6.—Extended Multiple System.**

With what is called the "closet" system the taps are all taken off at a few centrally located places, and in recesses in the wall may be set all the safety-fuses and the switches, so that the controlling may all be done from these few points. Figure 7 shows a system arranged in this way. This is the system used almost exclusively where the wiring is concealed. It requires more wire, but it does away with the safety-fuse blocks scattered about in unsightly and inconvenient places, and provides a special place for them in a receptacle that is unobtrusive.

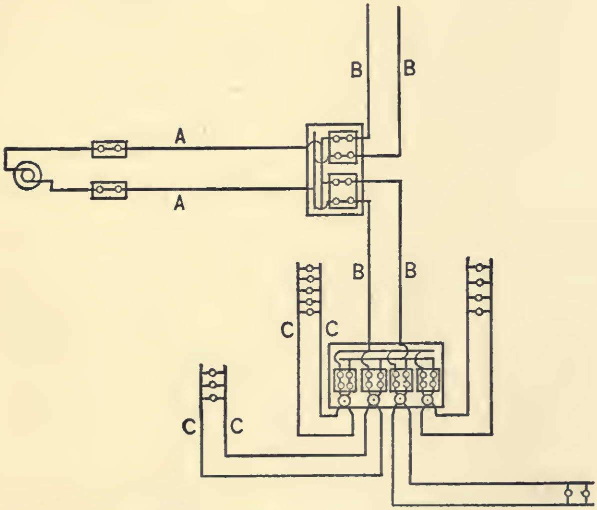

Fig. 7.—"Closet" System of Wiring.

The three-wire system is a special form of the multiple system and is largely used because it effects a great saving of copper. Figure 8 will serve to illustrate the principle. Two dynamos having the same voltage are used, and are connected as shown in the diagram. Suppose the voltage of each to be 110 volts. Then *A* is creating a difference of pressure between *c* and *d* of 110 volts, and *B* is creating a difference of pressure between *d* and *e* of 110 volts, so that there is a resulting difference of pressure between *c* and *e* of 220 volts. The "positive side" (or the side the current starts from) of *A* is the negative side (or the side the current returns to) of *B* just as it might be with two pumps, one creating a certain pressure and passing the water to the next, which adds a like pressure. If now the lamps were connected directly between *c* and *e*, the

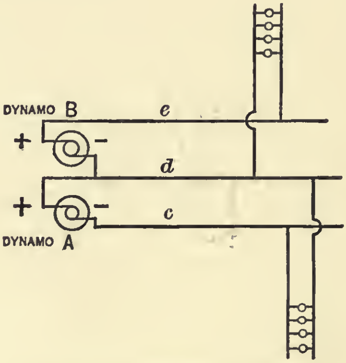

FIG. 8.—Three-wire System.

system would be working at a pressure of 220 volts, and, as indicated on page 34, the wire necessary to carry a current with a given per cent loss would be only one-fourth as much as would be necessary with one-half the voltage, or 110 volts. But with 220 volts it would be necessary to run two 110-volt lamps in series or to have 220-volt lamps. There are disadvantages in both these arrangements, however, that would counterbalance the advantage in the saving of copper, and 110-volt lamps are used with the two dynamos in the following way: —

The wire *d*, called the "neutral wire," is run with the other wires, *c* and *e*. Suppose that all the lamps are turned off, excepting one lamp between *e* and *d*. Dynamo *A* will have no work to do and will be running idle, while dyamo *B* will be supplying current to the one lamp through the wires *e* and *d* as if the circuit were a simple multiple system. But suppose now that a lamp is turned on between *c* and *d*. In the conventional way of speaking, dynamo *B* will be tending to send the current required by one lamp between *e* and *d*, from its positive side through the wire *e* to the lamp, and back through the wire *d* to the negative side of the dynamo; while dynamo *A*, on the other hand, will be tending to send the same strength of current for the lamp between *c* and *d*, from its positive side out through the wire *d*. The result of the tendencies is a neutralization. The current flows out on *e* through the two lamps back to *c*, just as it would if the wire *d* were not there at all and the two lamps were in series on a 220-volt circuit; but, since the wire is there, if anything happens to cause a break or a short circuit at either lamp, the other lamp will be run by its dynamo through the neutral wire, as in the ordinary two-wire system. The result is similar with any number of lamps on the two sides of the neutral wire. If there are 10 lamps between *d* and *e*, each requiring $\frac{1}{2}$ ampère, and 15 lamps between *c* and *d*, then dynamo *B* will tend to send a current of 5 ampères back along the neutral wire, and dynamo *A* will tend to send a current of 7$\frac{1}{2}$ ampères out along the neutral wire. The result will be a current of 2$\frac{1}{2}$ ampères out along the neutral wire, 5 ampères from dynamo *A* being neutralized by the 5 ampères from dynamo *B*.

In wiring a building for the three-wire system, the three wires are run together in the mains and branches, and the taps are taken off from the neutral wire and either of the other two in such a way that the loads on the two sides of the system will balance as nearly as possible. It is not possible in practice to get an absolute balance, but the neutral wire may frequently be only one-half or two-thirds the size of one of the outside wires. Even though the three wires are all the same size, there is only three-eighths as much copper used as would be necessary in the two-wire system running at the same voltage, with the same loss. For, as has been noticed, without the neutral wire the system is working at a pressure of 220 volts, and the copper required is only one-fourth as much as would be required with a system running at a pressure of 110 volts. If the neutral wire is the same size as one of the outside wires, the weight of copper is increased fifty per cent and becomes three-eighths as much as would be required with the 110-volt circuit.

# CHAPTER IV.

## METHODS OF WIRING.

SINCE electricity first came into general use there has been a constant improvement in the methods of wiring. Partly from an imperfect realization of the needs, and partly from the desire for cheap construction, all the early wiring was little more than a stringing of paths for the electricity to follow. It was soon found, however, that unless special precautions were taken to confine the current to these paths, there was danger of fire, and the service was poor and uncertain.

The first wiring was generally done with a wire inadequately covered, and the conductors were fastened directly against any convenient support by means of wooden cleats or iron staples. While everything was perfectly dry, and as long as the current was not greater than the wire could carry without excessive heating, little trouble would be found. But of course it was not possible to be sure of this dryness. Natural dampness in the atmosphere, leaky roofs, the accidental spilling of water, might at any time so affect the insulation that there would be considerable leakage. With this there would be, perhaps, a diminution in the available energy, and probably an arcing and heating that introduced a serious fire hazard.

There are two ways in which high temperatures are caused by electric currents. One is mentioned on page 13; it is the heating that takes place in any conductor when a current passes through it. A large current passing through a small conductor sometimes even causes fusion. But ordinarily much the higher temperature is produced by the formation of an electric arc, which is familiar from its practical use in the arc lamp. This arc is formed when a current passes from a conductor, through gases, to a conductor again, as explained on page 33. At ordinary potentials the current can "jump across" only a very short space, and these arcs have to be formed by the gradual separation of the conductors. Suppose that two wires when brought together complete an electric circuit; if the pressure forcing them together be now diminished, the electrical resistance at the contact is increased, and the current overcoming this resistance creates heat. If the wires are separated, there is at the instant of separation a great increase in the resistance and a proportionate increase in the heat generated; the ends of the conductors become volatilized and the result is an arc just like that formed with the carbons in the arc lamp.

A leaking current is likely to cause these arcs, because when a current passes by means of a semi-conductor, it often burns away small particles and is maintained by an arc from one conducting particle to another. When a current is once established it is not easily broken, and a distance that would have at first proved a complete barrier is easily bridged by the arc with its hot, semi-conducting gases. But leakages of this kind are not the only cause of destructive arcing. One wire may come in direct contact with the other wire of the circuit, or it may come in contact with a pipe or a bell-wire in accidental connection with the other side of the circuit; and in this case there may be a "short circuit" with a very heavy flow of current, or there may be a sputter, and a burning away of the metal in contact, which results in a long arc of intense heat.

Excessive currents in multiple systems are provided against, by the use of a small wire or strip of fusible alloy, which will melt and thus break the circuit before the current has had time dangerously to heat the copper wire. These fuses are supposed to be of sufficient length to make it impossible, when they melt, for the arc to hold across the gap in the circuit, and the fuse itself is enclosed in a non-combustible case that will not be injured by the momentary heat. In series circuits, where the current is of uniform strength, the fuse cannot be used; and even in a multiple system, if the fuse is not properly proportioned, a disastrous arc may form and be maintained.

The modern methods of wiring have accordingly been designed to prevent, as much as possible, the leakage of electricity and the formation of "short circuits"; to keep local the effects of these accidents when they happen; and to make it easy to repair defects. The underwriters now require all wires not encased in approved forms of moulding or in approved makes of conduit, to be supported wholly on non-combustible insulators. It is their intention that wires shall not even come in contact with anything else. They also have made stringent regulations with regard to the insulation that is to cover the copper wire. Manufacturers submit samples of their wire, and it is subjected to severe tests before the underwriters will approve its use. No wire is allowed in concealed work, or in places exposed to dampness, except of these brands that have been approved; but where the wire is entirely exposed and is in a perfectly dry place, a somewhat inferior insulation is allowed.

It was thought in the early days that wiring would be perfectly safe and satisfactory if it were simply buried in the plaster, or if it were strung through the spaces between floors and ceilings and in hollow walls. Though wire covered with a good insulation was often run in this way, a number of difficulties were soon met with. Carelessness in drawing the wire through confined places abraded or stripped the insulating covering; workmen sometimes pierced the insulation or even cut the wire, with nails and tools; and there proved to be alkalies and acids in the plaster that sooner or later broke down all resistance to electrical pressure. Moreover, these methods of wiring left no way to make repairs. In the event of a failure, there was no remedy but to tear the wire out of the plaster, or to pull it out of the spaces in the walls and ceilings, leaving no way to replace it.

There are now two approved methods of running wires for low potential circuits; they may be supported on non-combustible insulators, or they may be run in conduits. Wires may be run between floors and ceilings, in the hollow spaces in walls, or in any place one wishes, if the conductors are supported wholly on non-combustible insulators, such as glass or porcelain; if the wire has an approved insulating covering; and if in passing through walls, floors, timbers, ceilings, etc., proper insulating bushings are used. Wiring by this method can be made safe and satisfactory if the work is done conscientiously. Carelessness may, however, leave vulnerable places for the carpenter's nail; there is no certainty after the work is finished that it has been properly done; and it is difficult to replace wiring that from any cause becomes defective. The greater of these disadvantages may be overcome if the architect will make provisions for the free access to the wires as he sometimes does to pipes. Accessible wire ways on or in the walls should be provided for upright wires, and floors should be arranged so that any part of the horizontal wiring can easily be reached. When these precautions are taken, this method of wiring on insulators may be made safe, trustworthy, and convenient.

The greater part of the concealed wiring in the larger buildings is now done, however, in conduits. The building is first fitted with a system of waterproof, and to some extent fireproof, tubes, much as if a twin system of gas-pipes were being installed. These tubes lead from the mains to the branches, and from the branches to the lamps, and wherever a wire is to be connected to another wire, a "junction-box" is provided. The wires are then drawn through these tubes and the necessary connections made. The tubes are not depended upon for insulation, but are simply raceways for the wires, protecting their insulating covering from injury, and affording a confined channel through which new wires may, at any time, be drawn.

Aside from the accessibility, there is the advantage with this method, that though the conduit is installed at the time the building is erected, the actual wiring may be left until all carpenters and finishers have gone, and when there is no longer danger from carelessly driven nails or slashing tools. The space required for the conduits is less than that needed for porcelain insulators, which is of importance in the larger installations.

It seems probable that conduit, in some form, is the last stage in the development of concealed wiring. For some time it has been possible to get wire covered with an insulation of very good quality, and the trouble has been that this insulation was not protected from mechanical and chemical injury. A proper conduit will protect the insulation; it makes possible a more suitable time for running the wires; it gives compact construction and what may properly be called an electrical *system;* and it makes this system of wires capable of change or renewal at any time.

But with any method the electrical features should have consideration when the building is designed. This does not make necessary any great changes in construction or in arrangement, and a little attention given to desirable provisions makes the wiring installation a part of the whole building system rather than simply an adjunct; it also gives system to the wiring itself, and insures its being better and more convenient. Where conduits are used, the plaster may entirely cover the smallest tubes, but the larger mains require channels in the walls. In many cases, it is advisable to have the larger tubes in channels provided with removable covers, for the largest wires are not drawn in and out of the tubes with facility. Provision should also be made for the closets or pockets that are to hold the fuse-blocks and switches. These details are not unfrequently left for the electrical contractor, but there is, of course, a distinct advantage to both him and the architect to have cutting avoided where possible, and when it is necessary, to have it decided upon and arranged for beforehand.

# CHAPTER V.

## THE NATIONAL CODE OF RULES FOR ELECTRIC WIRING.

The rules for electric wiring that have been compiled and formulated by the underwriters have now become the accepted code throughout the country. Though the influence of the underwriters has, of course, done much to bring this about, there could not be the present broad acceptance, if the rules did not specify what experience has shown to be necessary for good and safe service.

One sometimes hears the criticism that these rules are the arbitrary prescriptions of men who know nothing about electricity, and who are carried away by fancied dangers. Such criticism is wide of the mark, and comes from erroneous ideas of the way in which the insurance code has grown. It is not an autocratic pronunciamento, but the result of a natural development. Starting with a few restrictions that were plainly necessary, the code has been gradually added to and expanded, as experience has shown the faults of practice. Many of the rules were adopted from the regulations enforced by the better class of electric companies, other rules have been suggested and formulated by some of the best-known engineers, and the underwriters now have a corps of electricians trained to judge of construction with regard to safety from fire, and competent to impose restrictions as new conditions are presented. If the rules were unreasonable, the electric-light companies would be the first to protest; but, on the contrary, the National Electric-Light Association has adopted virtually the same rules, and electrical engineers in general accept the insurance code as the best existing guide for safe construction. The complaint that comes from the better class of electrical men is not that the rules are too exacting, but that they are not always rigidly and consistently enforced.

Architects can, of course, do much to insure good electrical construction in their buildings, but they have usually paid little attention to this feature. It is very common to find in the architect's specifications a clause requiring "all work to be done in strict compliance with the underwriters' rules," and then to find, following this, a number of clauses specifying construction that is explicitly prohibited by the rules. With this evidence of ignorance before them, it is not surprising that contractors often feel free to do the work as they please.

The rules are necessarily short, and naturally there are many technical terms used. It has seemed that it would be helpful to have these terms defined, and to have the reasons for the rules briefly stated. Accordingly, the latest rules of the National Board of Fire Underwriters, as amended at New York, January, 1895, are taken up here. The rules, which are printed in small type, must be read continuously to get the full meaning, since the remarks are interpolated. The advantages in taking up a few rules at a time seemed greater than the disadvantages in having sometimes to refer to the last sub-heading in order to find the subject.

## Class A.

### CENTRAL STATIONS.—FOR LIGHT OR POWER.

These rules also apply to dynamo rooms in isolated plants, connected with or detached from buildings used for other purposes; also to all varieties of apparatus therein, of both high and low potential.

**1. Generators:**

*a.* Must be located in a dry place.

*b.* Must be insulated on floors or base frames, which must be kept filled, to prevent absorption of moisture, and also kept clean and dry.

*c.* Must never be placed in a room where any hazardous process is carried on, nor in places where they would be exposed to inflammable gases, or flyings of combustible material.

*d.* Must each be provided with a waterproof covering.

A "generator" receives mechanical energy at the pulley, and gives out electrical energy; a "motor" receives electrical energy and gives out mechanical energy at the pulley. Strictly speaking, both are "dynamos," or dynamo electric machines, but the term "dynamo" is commonly used as synonymous with generator.

"Potential" is used in the rules as synonymous with electrical pressure; voltage; electro-motive force: the virtue by which an electric current is forced through a wire or other substance. "High" and "low" potential are, of course, relative terms, but in these rules a high potential is that measuring over 300 volts, and a low potential is that measuring 300 volts or less.

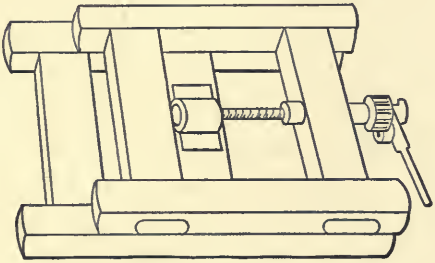

FIG. 9.—Base Frame.

The "base frames," on which dynamos are usually set, are simply heavy frames of wood, filled, or impregnated, with oil or other insulating substance that will prevent moisture from penetrating the pores of the wood. If moisture were to penetrate, it would make a semi-conductor of the wood through which currents of electricity might leak. The frames on which the smaller machines are set are usually made in two parts, the top part being adjustable so that the belt may be tightened by moving the machine.

Almost all damp substances are fairly good conductors, and even damp and dirty surfaces will allow considerable leakage. Precautions have to be taken against the beginning of these small leaks. They rapidly become worse, for they are accompanied by heating and sparking which carbonizes surrounding substances, making it possible for still larger currents to flow. If the wires of a dynamo become damp, there is apt to be leakage from one wire to another across the damp insulation, and once started, there will soon be a path of very low resistance, or a "short circuit," that will result in a current heavy enough to melt metal and destroy the usefulness of the machine. Trouble comes in another way, if the dynamo be damp and not well insulated from the ground: though the circuit is supposed to be insulated from the ironwork of the machine, there is liability of a connection, and if the wooden frame under the dynamo be damp and partly conducting, the circuit will be more or less well connected with the earth through the ironwork, wood, masonry, etc.

Suppose, in Figure 10, there is a connection to the iron of the dynamo near *B*, and a path thence through wet wood to a bolt, and then to the earth at *E*. If this be all, no current will flow, for there is no path up from the earth to the other wire of the circuit. Suppose, however, that somewhere in a building there is a gas-pipe in electrical connection with the other wire of the circuit, as at *A*. The gas-pipe runs, of course, to the earth, and the current then has a path through pipe, earth, bolt, wet wood, and the iron of the dynamo, between the two sides of the circuit, *A* and *B* There is thus the full electrical pressure of the dynamo to force the current through this path, and a hole may be burned in the gas-pipe, with easily imagined result.

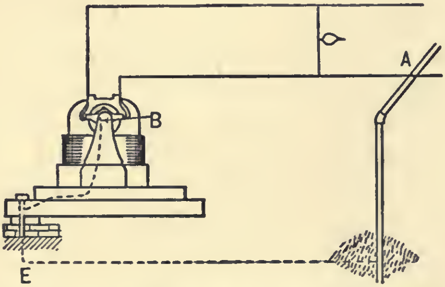

FIG. 10.—Showing Effect of Ground Connections.

A dynamo often emits small sparks, and when working badly throws out bits of molten metal, so that it is evidently unsafe to have the machine placed where there is inflammable matter.

The waterproof cover that is required, serves to keep the dynamo clean and dry under ordinary conditions, and will be ready to use in case of a leak above the machine or for protection from water damage in case of a fire.

### 2. Care and Attendance:

A competent man must be kept on duty in the room where generators are operating.

Oily waste must be kept in *approved* metal cans, and removed daily.

[*Approved* waste cans shall be made of metal, with legs raising can three inches from the floor, and with self-closing covers.]

### 3. Conductors:

From generators, switch-boards, rheostats or other instruments, and thence to outside lines, conductors —

*a.* Must be in plain sight, and readily accessible.

*b.* Must be wholly on non-combustible insulators, such as glass or porcelain.

*c.* Must be separated from contact with floors, partitions, or walls, through which they may pass, by non-combustible insulating tubes, such as glass or porcelain.

*d.* Must be kept rigidly so far apart that they cannot come in contact.

*e.* Must be covered with non-inflammable insulating material sufficient to prevent accidental contact, except that "bus-bars" may be made of bare metal.

*f.* Must have ample carrying capacity, to prevent heating. (See Capacity of Wires Table, page 135.)

The "switch-board" is the frame, board, partition, or slab on which are grouped the different instruments, and the devices for controlling the dynamos and for properly distributing the currents to the different circuits. (Page 64.)

A "resistance-box" contains usually a number of coils of wire, and its object is to introduce into the electric circuit a resistance that will reduce the strength of the current. It is thus a sort of electrical throttling device. A "rheostat" is an adjustable resistance-box. An "equalizer" is a resistance-box or rheostat used for the special purpose of equalizing conditions in different parts of a circuit. "Resistance-box" is the general term and is applied to all this species of apparatus. (Page 66.)

There are innumerable types of "insulators" for supporting wire, and they vary in shape according to the special purpose for which they are used. Sketches of a few of them are given in Figures 11–14.

Where wires pass through floors, walls, and such places, there is particular liability to dampness, and to contact with material that offers a path for leakage. In such places, there is also liability that the insulation on the wire will become abraded in drawing the wire through, or that it will gradually be abraded by the movement of the wire afterward. For protection in these places "insulating-tubes" are used. There is a flange on one end to prevent the tube from sliding through the hole. (Fig. 14.)

The "bus-bars," or omnibus bars, are the main conductors from which the smaller wires lead off to the different circuits in the building or city. The bus-bars are placed on the switch-board, usually at the back. (Fig. 15.)

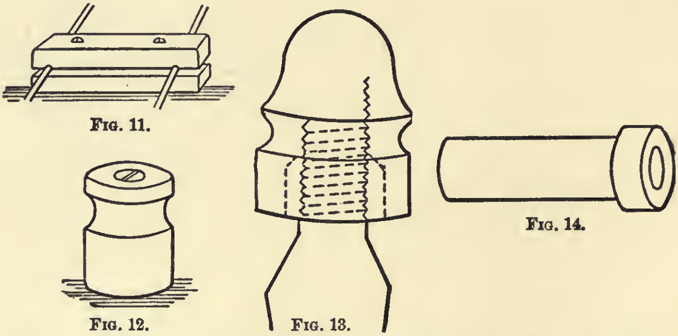

Fig. 11.—Porcelain Cleat. Fig. 12.—Porcelain Knob. Fig. 13.—Petticoat Insulator. Fig. 14.—Insulating-tube.

The "carrying capacity," or safe carrying capacity, of a conductor is the amount of current it will carry without heating to an unsafe temperature. A certain temperature is fixed upon, and there is determined for each size of wire the current that in passing through it will heat it to this maximum allowable temperature. The results of these experiments are embodied in a table of safe carrying capacities for all sizes of wire commonly used. (Page 135.)

In dynamo rooms the conductors are usually numerous and very compactly placed, so that there is need of special precaution in construction. Moreover, the wires are the main conductors of the wiring system, and any devices protecting them work only when the full capacity of the system is exceeded. Short circuits or leaks would consequently be more serious in their effects. In a part of the dynamo-room wiring, it is not practicable to have safety devices, and where so much has thus to be trusted to insulation and non-combustibility, the only satisfactory construction is

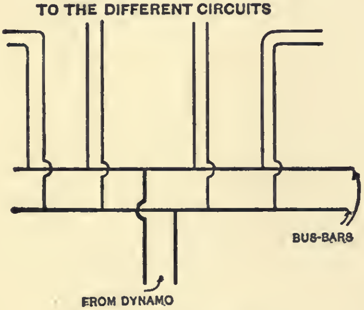

FIG. 15.—Bus-bars.

to have the wires in contact with nothing but glass, porcelain, slate, or similar material.

Bus-bars are in a place where they are not exposed to contact with foreign substances, but they are to be supported on non-combustible material, as there is a possibility of their overheating.

### 4. Switch-boards:

*a.* Must be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material.

*b.* Must be accessible from all sides when the connections are on the back; or may be placed against a brick or stone wall when the wiring is entirely on the face.

*c.* Must be kept free from moisture.

*d.* Must be made of non-combustible material, or of hard wood in skeleton form, filled to prevent absorption of moisture.

*e.* Bus-bars must be equipped in accordance with Rule 3 for placing conductors.

[Section *a.* Special attention is called to the fact that switch-boards should not be built down to the floor, nor up to the ceiling, but a space of at least eighteen inches, or two feet, should be left between the floor and the board, and between the ceiling and the board, in order to prevent fire from communicating from the switch-board to the floor or ceiling, and also to prevent the forming of a partially concealed space very liable to be used for storage or rubbish and oily waste.]

A switch-board in "skeleton form" is one built as a frame-work, in distinction from a solid board or partition. It gives good ventilation, has a minimum amount of combustible material, and affords little opportunity for leakage. (Fig. 16.)

The switch-board has on it a number of devices controlling the full power of the dynamos, and there is here the full electrical pressure. These conditions often expose the switch-board to intense heat, and sometimes shutting down the machinery is the only way to stop the cause. It is consequently best to have everything about the switch-board of non-combustible material, even to the supports for the slate or marble slabs. With the high potentials that are

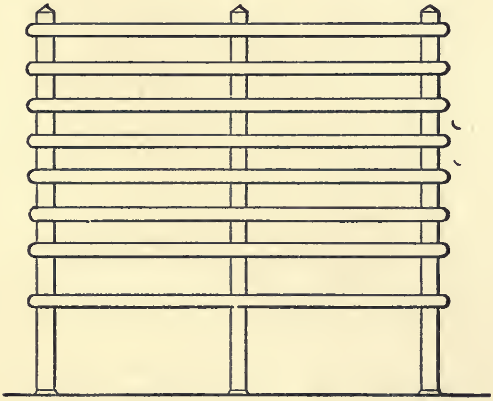

Fig. 16.—Switch-board in Skeleton Form.

brought to this point, it is necessary, too, that the board be perfectly dry and clean, and that the material of which the slabs are made does not have conducting veins in it. All the leakage effects are greatly increased with high potential, and even slate slabs have been known to split into many pieces from heat generated by leakage through metallic veins.

**5. Resistance-boxes and Equalizers:**

*a.* Must be equipped with metal or other non-combustible frames.

*b.* Must be placed on the switch-board, or if not thereon, at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

[Section *a.* The word "frame" in this section relates to the entire case and surrounding of the rheostat, and not alone to the upholding supports.]

Resistance-boxes, even in normal working, develop heat, for their office is to introduce resistance into the circuit, and all the energy necessary to overcome this resistance is converted into heat. It is not only a possibility, therefore, that is here to be guarded against, but an actual normal condition. Moreover, as many of the resistance-boxes are made, there is liability of the coils of wire coming together, forming shorter paths for the current and thereby causing much greater temperature than was anticipated. There is clearly but one way to treat this piece of apparatus, and that is to have it wholly non-combustible, and arranged so that it can do no harm even if it heats excessively. As the coils may accidentally become connected to the metal frame, it is well to have the frame insulated as the rules indicate.

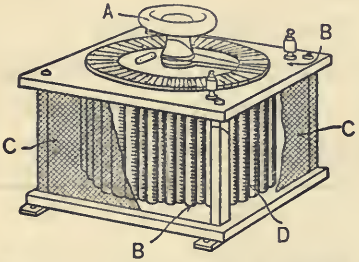

**Fig. 17.—Resistance-Box or Rheostat.**
**A, Handle for adjusting resistance. B, Slate top and back. C, Screen allowing ventilation. D, Coils.**

**6. Lightning-arresters:**

*a.* Must be attached to each side of every overhead circuit connected with the station.

*b.* Must be mounted on non-combustible bases in plain sight on the switch-board, or in any equally accessible place, away from combustible material.

*c.* Must be connected with at least two "earths" by separate wires, not smaller than No. 6 B. & S., which must not be connected to any pipe within the building, and must be run as nearly as possible in a straight line from the arresters to the earth connection.

*d.* Must be so constructed as not to maintain an arc after the discharge has passed.

A "lightning-arrester" would perhaps more properly be called a lightning diverter, since it does not arrest the lightning, but diverts it from the wiring by offering a comparatively easy path to the earth. If there were not this easy path, the lightning would pierce the insulation in some other place, because of the great force urging a discharge. The lightning-arrester is made so that the connection with the earth is broken as soon as the lightning or "static discharge" has passed, for otherwise there would be an opportunity for the leakage of the dynamo current.

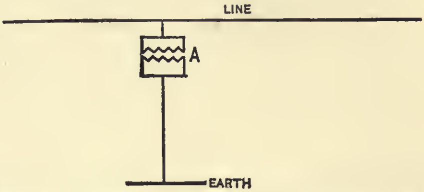

FIG. 18. — Showing Principle of Lightning-arrester.

Figure 18 shows the principle of a lightning-arrester. At *A* is a very short air-space that is an effectual insulator as far as the normal electrical pressure on the line is concerned. When a lightning charge accumulates on the line there is a very strong tendency for it to break through the insulation to the earth, and the short air-space is easily sparked across. The air is heated somewhat by the discharge, and the normal electrical pressure on the line is sufficient to maintain a constant leakage to the earth if there is not some arrangement that breaks the connection. This connection can be broken in several ways. Often the arrester is made so that after a discharge the air-space is increased until the electrical pressure can no longer force a current through it, and sometimes a strong magnet is directed across the space; it being a curious fact that a magnet will repel an arc and thus "blow it out."

"Each side" of the circuit means each wire of the circuit; the one going out and the one coming in.

An "earth" is a connection with the earth, or the special arrangements, such as buried metal, pipes, etc., that insure the electrical connection. A good earth is made by imbedding a copper or iron plate about two feet square in broken coke and burying the whole in moist earth. All connections should be soldered.

The wire gauge of Brown & Sharpe is the one by which copper wire is usually measured in this country, and it is commonly called the "B. & S. gauge."

The electric "arc" has been explained. (Pages 33, 47.) It is familiar in the arc lamp. A current of electricity in being forced through an air-space meets a high resistance, and the energy required to force the current through this resistance is transformed into intense light and heat. The heated air and volatilized substances make of the space a conductor to some extent, but one with a comparatively high resistance.

Lightning discharge currents do not act the same as the currents from dynamos. They do not always take the path that would be taken by a dynamo current, but frequently jump across spaces of air rather than go round corners and bends in conductors. It is consequently important that the path from the lightning-arrester to the earth be straight, so that the lightning discharge will not cause damage on its way to the earth. Though arresters are made to break automatically the connection with the earth as soon as the discharge current has passed, a heavy discharge may prove too much for the arrester and the arc be long continued. For this reason, everything about the arrester should be non-combustible. Since parts of the arrester have good connection with the earth, special care must be taken to prevent leakage, and consequently the base on which the parts are mounted should be of a material that will not absorb moisture.

The two earths are required to assure good and sufficient connection with the earth. It is bad practice to connect to pipes in a building, because there is then no certainty that the discharge current will go to the earth without damage in some unlooked-for place.

**7. Testing:**

*a.* All series and alternating circuits must be tested every two hours while in operation, to discover any leakage to earth, abnormal in view of the potential and method of operation.

*b.* All multiple-arc low-potential systems (300 volts or less) must be provided with an indicating or detecting device, readily attachable, to afford easy means of testing where the station operates continuously.

*c.* Data obtained from all tests must be preserved for examination by insurance inspectors.

These rules on testing to be applied at such places as may be designated by the association having jurisdiction.

A "series circuit" is one in which everything in the circuit, — dynamo, wire, lamps, etc., — comes one after the other, "in series"; the same current going through each. (Fig. 19.)

The electrical pressure necessary to force the current through such a circuit is usually high, because each device requires a certain pressure, and the total pressure on the circuit must be the sum of the pressures required by the different devices. The high pressure, of course, makes leaks more probable and more disastrous. (Page 31.)

In "alternating circuits" the current alternates in direction. Such a circuit has peculiar properties that make it possible, where branches are taken off, to change the pressure with transformers to anything desired. With alternating circuits the pressure between the wires that leave the station is high, and this system is consequently classed with series systems. (Page 154.)

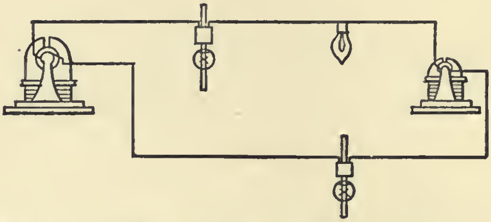

FIG. 19.—Series Circuit, showing Same Current passing through Lamps and Motor.

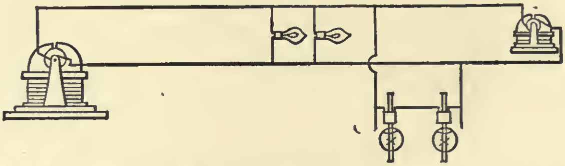

FIG. 20.—Multiple Circuit, showing Lamps and Motor working with Constant Pressure.

In the "multiple-arc" system, or, better, the multiple system, there is a constant pressure between the main wires, and the different devices are connected-in between the wires, each device operating at the full pressure of the system and taking only such current as the resistance of the device allows. (Fig. 20.)

The pressure between the mains of a multiple system — except alternating circuits—is usually below 300 volts, and is consequently "low," but there are often multiple circuits on which motors are operated, that have a pressure of 500 volts. (Page 36.)

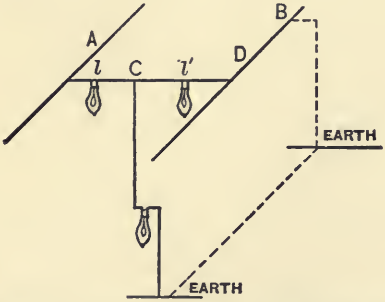

**Fig. 21.**—A Form of Ground-detecting Device.

"Detecting" or "indicating devices" are arranged to operate by the leakage current. A simple form that will serve as an illustration, is as follows: —

Suppose that in Figure 21, *A* and *D* are the main wires of a multiple system, and that *l* and *l′* are two incandescent lamps connected-in between the mains, but in series. They will not burn brightly, because instead of each lamp's getting the full pressure, each gets only one-half. At *B* suppose there occurs an accidental connection with the earth. If now there be a permanent ground-connection at *C*, the current that passes through *l* does not all go through *l′*, but can partly, at least, leak through the earth, up to *B* and thence to *D*. As a result, less current than before the accidental connection occurred will go through *l′* and more than before through *l*. This will, of course, make *l* brighter and *l′* less bright. Thus when the left-hand lamp burns brighter, there is a leakage to the ground on the right-hand wire, and when the right-hand lamp burns brighter, there is a leakage on the left-hand wire. A lamp may also be put in the wire leading to the ground. This lamp will then light up more or less, according to the amount of the leakage.

## MOTORS.

**8. Motors:**

*a.* Must be wired under the same precautions as with a current of the same volume and potential for lighting. The motor and resistance-box must be protected by a double-pole cut-out and controlled by a double-pole switch, except in cases where one-quarter horse-power or less is used on low-tension circuit, a single-pole switch will be accepted.

*b.* Must be thoroughly insulated, mounted on filled dry wood, be raised at least eight inches above the surrounding floor, be provided with pans to prevent oil from soaking into the floor, and must be kept clean.

*c.* Must be covered with a waterproof cover when not in use, and, if deemed necessary by the Inspector, be enclosed in an *approved* case.

[Section *c.* From the nature of the question, the decision as to what is an *approved* case must be left to the Inspector to determine in each instance.]

**9. Resistance-boxes:**

*a.* Must be equipped with metal or other non-combustible frames.

*b.* Must be placed on the switch-board, or at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

[Section *a.* The word "frame" in this section relates to the entire case and surrounding of the rheostat, and not alone to the upholding supports.]

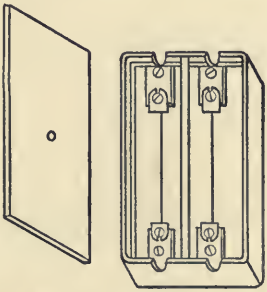

FIG. 22.—Double-pole Cut-out.

"Cut-out" here means fusible cut-out. Generally speaking, a cut-out is any device that makes a break in the circuit and "cuts out" any lamp, motor, or other piece of apparatus. The term is, however, becoming commonly applied to fusible cut-outs only. The fusible cut-out ordinarily consists of a block or box of porcelain arranged so that a "fuse," or piece of easily fusible metal, will form a part of the circuit. When the current becomes too great, the fuse melts, because of the heat that the current generates in it, and the circuit is thus broken. This fuse is supposed to be so proportioned that it will melt before the copper conductors can become unduly heated by an excessive current. The fusible cut-out is frequently called a "fuse-block."

A "double-pole" device is one that acts in each of the two poles, two wires, or two sides of a circuit. It is required that cut-outs and switches be double-pole so that the cutting-off will be complete and certain.

Suppose that, as in Figure 23, the fuse is single-pole, that is, acting on one wire of the circuit only. A heavy current flowing through the circuit will, of course, melt the fuse and the flow be stopped. But suppose that the fuse is just inside the wall of the building, and that the wire *A* outside the wall comes into connection with a metal column or with some other conductor connected with the earth. Suppose, moreover, that there is a connection with the ground on account of poor insulation at the motor, or that the wire comes in contact with a gas-pipe somewhere along *BC*. (Page 59.) Then the earth will be a by-path or "shunt" round the fuse and will make a closed circuit even though the single-pole switch be open. In this case a large part of the wire will not be protected by the fuse at all. A double-pole cut-out or double-pole switch will, however, cut off all the circuit beyond it, as may be seen by comparing Figures 23 and 24.

The "switch" is a device that operates mechanically, and is simply an arrangement by means of which one can pull out of circuit, metal that bridges over a gap. An air-space or some other insulation is left, over which the current cannot pass.

When the circuit is broken, there is an arc at the point of separation. If the circuit be broken at only one point, the arc will be greater than if there are several points of separation. With a double-pole switch having two breaks in each pole, there is thus much less arcing upon opening, than if the switch has a single-pole with one or two breaks. With a small motor running on a low-potential circuit, the current is small and the pressure low, so that the arc formed

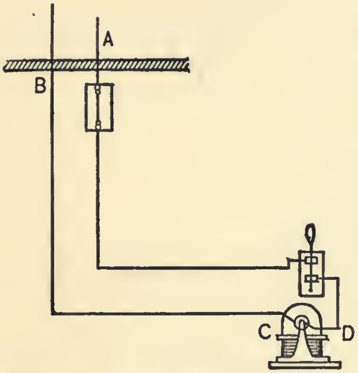

**Fig. 23.**—Showing Single-pole Cut-out and Single-pole Switch.

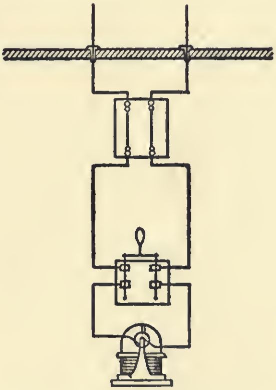

**Fig. 24.**—Double-pole Cut-out and Double-pole Switch.

when the circuit is broken is inconsiderable. It is also of little importance here, that the switch cut off completely all the wiring beyond it. For these reasons the rules allow single-pole switches under the conditions stated.

The motor must be insulated from the ground for the same reasons that apply to the generator. (Page 58.) A motor is, however, used in all sorts of places and usually has not a special space set apart for it as a generator has, so there is need of greater precaution. Mounting the motor on filled dry wood and raising it eight inches from the surrounding floor keeps it well insulated, away from dirt that might gather on the floor, and less liable to water damage in case the floor becomes flooded during a fire. Drip-pans are required so that all surplus oil may be caught, and everything about the machine thus kept clean and less combustible.

The waterproof cover serves the same purpose that it serves in the case of the generator. (Page 60.)

Rule 1 (*c*) requires that a generator shall not be placed in a room where there are flyings of combustible material. It is obviously not always practicable to confine motors to rooms altogether free from this sort of thing, and where there is dust or dirt, or flyings of any kind, the motor is enclosed in a case that will isolate it from bad conditions. Usually the case advised by the underwriters is a small room or closet built about the motor and lined with sheet metal.

Rules 9 (*a*) and 9 (*b*) are made for the reasons that 5 (*a*) and 5 (*b*) are made. In the case of a motor, however, a wooden resistance-box is still more unfit, for it is used only in starting the motor, and resistance is not supposed to be left in circuit, but to be all cut out as the motor reaches full speed. When through carelessness or accident some of the resistance is left in circuit, the coils are very likely to overheat, for they are frequently of too small carrying capacity to carry for any length of time the current that will flow through them.

## Class B.

### HIGH-POTENTIAL SYSTEMS. — OVER 300 VOLTS.

**Any circuit attached to any machine, or combination of machines, which develops over 300 volts difference of potential between any two wires, shall be considered as a high-potential circuit and coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to less than 300 volts.**

**10. Outside Conductors** — All outside, overhead conductors (including services):

*a*. Must be covered with some *approved* insulating material, not easily abraded, firmly secured to properly insulated and substantially built supports, all tie-wires having an insulation equal to that of the conductors they confine.

[Section *a*. Insulation that will be *approved* for service-wires must be solid, at least three sixty-fourths of an inch in thickness, and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahr., and three days' submersion in lime-water, with a current of 550 volts, and after three minutes' electrification.]

[The following list of wires have been tested and found to comply with the requirements for an approved insulation under Rule 10 (*a*), Rule 12 (*d*), and Rule 18 (*a*): —

Acme, Ajax, Americanite, Bishop, Canvasite, Clark, Columbia, Crescent, Crown, Edison Machine, Globe, Grimshaw (white core), Habirshaw (red core), Kerite, National India Rubber Company (N. I. R.), Okonite, Paranite, Raven Core, Safety Insulated: Requa white core, Safety black core; Salamander (rubber covered), Simplex (caoutchouc), United States (General Electric Company).

None of the above wires to be used unless protected with a substantial *braided* outer covering.]

"Services," or service-wires, are the wires that lead from the main distributing wires to any special installation, just as the service water-pipes are the small pipes that lead from the street mains to a building.

"Tie-wires" are the short pieces of wire that are used to tie or fasten the line-wire to the insulators. (Fig. 25.)

*b.* Must be so placed that moisture cannot form a cross-connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports.

*c.* Must be at least seven feet above the highest point of flat roofs, and at least one foot above the ridge of pitched roofs over which they pass or to which they are attached.

*d.* Must be protected by *dead insulated guard irons* or *wires* from possibility of contact with other conducting wires or substances to which current may leak. Special precautions of this kind must be taken where sharp angles occur, or where any wires might possibly come in contact with electric-light or power wires.

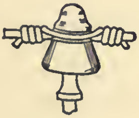

FIG. 25.
Tie-wire.

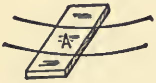

FIG. 26.
Cross-connection.

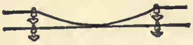

FIG. 27.
Cross-connection.

A "cross-connection" might perhaps be quite as well termed simply a connection. Thus, in Figure 26, if both wires are lying on the wet wood, *A*, there may be sufficient leakage through the wood to form an electrical connection, or cross-connection, between the two wires.

In a similar way, if the two wires in Figure 27 were fastened to the front of a building, and the upper wire were to become loose and to hang near the lower, water dripping from the upper wire might be the cause of a connection between the two.

Long stretches of wire are apt to sag, and to make sure that this sagging will not bring the wire in contact with roofs, the provisions in Rule 10 (*c*) are made.

"Guard-irons" are used to keep a wire from coming in contact with conducting material when the wire fails to be properly supported by its insulators. Thus, in Figure 28, where a wire is passing round the corner of a building, if the pin holding the insulator *A* should break, the attached wire would, on account of the strain upon it, come against the wires *B* if there were not the guard-iron, *C*, to catch it.

If a wire passes over another wire, and there is any liability of the upper wire's sagging, coming loose from its fastenings, or breaking, a guard-wire, fastened to insulated supports and passing under the upper wire, will receive this upper wire if it fall, and will prevent its falling on the wire below.

Wires that carry current for running motors, or for furnishing power in distinction from light, are commonly called "power-wires."

*e.* Must be provided with petticoat insulators of glass or porcelain. Porcelain knobs or cleats and rubber hooks will not be approved.

*f.* Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

[Section *f.* All joints must be soldered, even if made with the McIntyre or any other patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.]

*g.* Telegraph, telephone, and similar wires must not be placed on the same cross-arm with electric light or power wires.

**11. Service-blocks:**

Must be covered over their entire surface with at least two coats of waterproof paint.

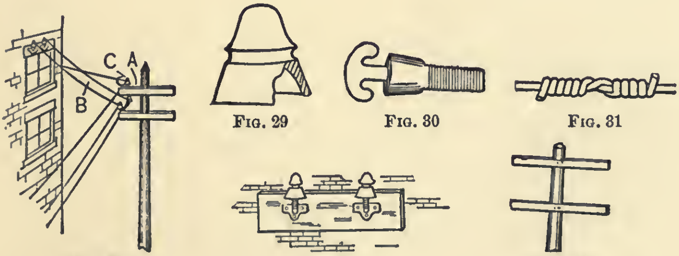

Fig. 29 Fig. 30 Fig. 31

Fig. 28 Fig. 32 Fig. 33

Fig. 28.—Showing Guard-iron. Fig. 29.—Petticoat Insulator. Fig. 30.—Rubber Hook. Fig. 31.—Twisted Joint. Fig. 32.—Service-block. Fig. 33.—Cross-arms.

The "petticoat-insulator" has a petticoat, or lip, round the bottom. (Fig. 29.) There may be leakage over wet surfaces, but with the petticoat insulator the inside surface of the petticoat is protected from the weather and is always dry. Thus the current cannot leak from the wire to the ground since it would have to cross this dry surface in order to reach the wooden pin on which the insulator is screwed, and this pin affords the only path to the earth.

Figure 12 shows a "porcelain knob." Dry porcelain is one of the best of insulators, but the knob has all its surface exposed to the weather, and when wet there may be considerable leakage over this surface. Porcelain also sometimes absorbs moisture.

The "porcelain cleat" (Fig. 11) and the "rubber hook" (Fig. 30) are objectionable for outside work, for the same reason that knobs are objectionable.

Figure 31 shows a "twisted joint" that will be secure without solder and that will insure good electrical connection. If left simply twisted in this way, or even if covered, the copper would soon become tarnished with a thin layer of poorly conducting substance. This would impair the connection and introduce into the circuit a certain amount of resistance that would perhaps be the cause of considerable heating. To make a permanently good joint, it is necessary to solder it thoroughly.

"Service-blocks" are the blocks of wood to which the insulators holding the service-wires are attached. The object of the waterproof paint is simply to give a safeguard against the absorption of moisture by the wood, which would make it a conductor and thus increase the liability of leakage. (Fig. 32.)

There is, of course, more liability of accidental contact between wires where they are near together, as they would be when attached to the same cross-arm. There is also more liability of a connection between the two circuits on account of leakage through a wet cross-arm. Only low electrical pressures are required to operate telephone, telegraph, and similar circuits, and since less care is usually taken with their insulation, even slight leakages to them, of light or power currents, might prove dangerous.

It will be observed that most of the provisions in Rules 10 and 11 are made for the purpose of securing good insulation. Wires and supports out of doors are, of course, often exposed to thorough soaking, and wind storms bring strains upon the supports, swing wires out of position and rub them against awning frames, cornices, etc., so that the greatest precaution must be taken if the insulation of the circuit is to be at all times preserved.

A proper insulating covering on the wire will prevent leakage as long as the covering is in its original condition. It is a protection against leakage that comes from accidental contacts with conducting material, and prevents much of the trouble that arises with inferior coverings. When, however, the covering rubs against stonework or other substances, as it often does when the wire is moved by the wind, the covering is soon abraded so that the bare wire is exposed to contact. Thus, though the insulating covering gives security in many cases, it cannot be depended upon exclusively, and precautions must be taken against contacts with any foreign substances and also against the possibility that dampness will cause leakage at some point where the covering has been injured.

### INTERIOR CONDUCTORS. — (HIGH-POTENTIAL SYSTEMS.)

**12. All Interior Conductors:**

*a.* Must be covered where they enter buildings from outside terminal insulators to and through the walls, with extra waterproof insulation, and must have drip-loops outside. The hole through which the conductor passes must be bushed with waterproof and non-combustible insulating tube, slanting upward toward the inside. The tube must be sealed with tape, thoroughly painted, and securing the tube to the wire.

*b.* Must be arranged to enter and leave the building through a double contact service-switch, which will effectually close the main circuit and disconnect the interior wires when it is turned "off." The switch must be so constructed that it shall be automatic in its action, not stopping between points when started, and prevent an arc between the points under all circumstances; it must indicate on inspection whether the current be "on" or "off," and be mounted in a non-combustible case, and kept free from moisture, and easy of access to police or firemen. So-called "snap-switches" shall not be used on high-potential circuits.

*c.* Must be always in plain sight, and never encased, except when *required* by the Inspector.

*d.* Must be covered in all cases with an *approved* non-combustible material that will adhere to the wire, not fray by friction, and bear a temperature of 150 degrees Fahr., without softening.

[Section *d.* Insulation that will be *approved* for interior conductors must be solid, at least three sixty-fourths of an inch in thickness, and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahr., and three days' submersion in lime-water, with a current of 550 volts, and after three minutes' electrification.]

[See List of Wires, page 80.]

*e.* Must be supported on glass or porcelain insulators, and kept rigidly at least eight inches from each other, except within the structure of lamps or on hanger-boards, cut-out boxes, or the like, where less distance is necessary.

*f.* Must be separated from contact with walls, floors, timbers or partitions through which they may pass, by non-combustible insulating tube.

*g.* Must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

The "terminal insulators" are the last insulators to which the wire is attached outside the building and from which the wire is led through the walls. (Figs. 34 and 35.) The wire from these insulators and thence through the wall is to have extra waterproof insulation, because it is this part of the circuit that is most likely to be near cornices, awnings, etc., and because in passing through holes exposed to moisture there is liability of leakage.

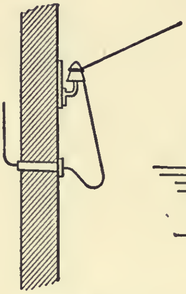

Fig. 34.

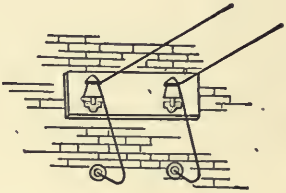

Fig. 35.

Showing Service Entrance.

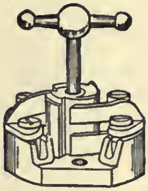

Fig. 36.

Snap-switch without cover.

"Drip-loops" are loops in the wire just before it enters the building. (Figs. 34 and 35.) Water gathering on the wire will run to the lowest point, and where there are drip-loops this water will drip off instead of running into the holes in the wall, which would increase the danger of leakage.

It is required that the holes, through which the wires pass, be bushed with non-combustible "insulating-tubes" made of glass, porcelain, or similar material (Fig. 14) because time and exposure do not cause their deterioration; and when, for any reason, leakage does occur over their surfaces, they will not char or burn, or become better conductors. The tubes are slanted upward toward the inside of the building so that there will be no tendency for the water to enter.

Moisture is further provided against by winding about the wire and the end of the tube "tape" made of insulating material. This tape is adhesive and can be made effectually to seal the end of the tube, if it be afterward thoroughly painted with waterproof paint.

A "service-switch" is a switch in the service-wires, by which all connection between the main distributing wires in the street and the wiring in the building may be broken. (Page 80.)

"Snap-switch" is the name given to the small circular switches ordinarily used to turn incandescent lamps on and off. One form is shown in Figure 36. When the handle is moved slightly, a spring of considerable strength comes into play and snaps the switch into position, thus breaking or making the circuit quickly and preventing the longer arc that would form if the switch were thrown into position by the slow movement of the hand.

The "hanger-board" is the slab of insulating material fastened to the ceiling, from which an arc lamp is hung. (Figs. 43 and 44.) The board usually has mounted on it, connection-blocks for the wires, and a switch by which the current may be cut off from the lamp. (Page 98.)

The term "cut-out" in Rule 12 (*e*) refers to the service-switch, and the cut-out box is the box in which the working parts of the service-switch are placed.

The object of the service-switch is, as the rules state, to disconnect the interior wires from the main wires in the street. By this means, current can be excluded from the building at all times when it is not being used, and if, while current is being used, a defect in the insulation or in the operation of the apparatus develops, the current can immediately be cut off before it has time to do any damage. This safeguard is particularly necessary with series circuits, for the dynamos in this case are so regulated that they tend to keep a constant current flowing, whatever resistance is brought into the circuit. Thus when a series circuit is broken, the pressure at the dynamo tends to increase so that the current may be maintained even through the air-space introduced by breaking the circuit. This, of course, causes a long and dangerous arc. Since in the series circuit the same current passes through all lamps and other devices, breaking the circuit shuts off the current from every device operated by the dynamo. Consequently, with the series circuit, a form of switch must be used that will first give a new path for the current and then cut the current off from the old path. (Pages 28, 31.)

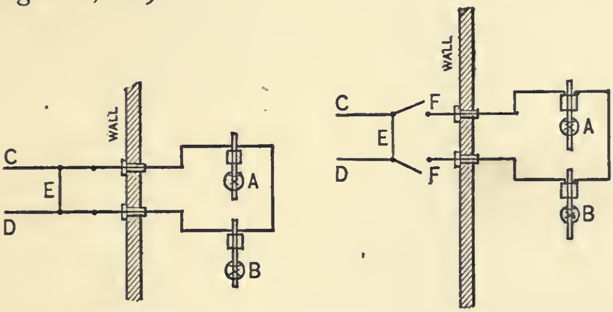

Fig. 37. Fig. 38.

Illustrating Principle of Service-switch in Series Circuits.

The principle of the switches that are used is illustrated in Figures 37 and 38. Suppose the lamps *A* and *B* are in a building having a service-switch just outside the point of entrance. When the current is cut off from the lamps, it is necessary that the switch first make a connection, or by-path, directly across the two wires *C* and *D*, as in Figure 37. The current now divides, part still going through the lamps, but the greater part through the cross-connection *E*, because it offers less resistance. The next action of the switch is to break all connection with the wires leading to the lamps, while the cross-connection *E* is still maintained. (Fig. 38.)

The circuit having been at no point interrupted, the other devices in the circuit are not interfered with, and there is no arc formed during the change. A switch that performs the two actions shown in Figures 37 and 38 is called a "double-contact" switch because there are simultaneously two contacts, one with the wires leading to the lamps and one forming the by-path. If these two contacts do not exist at the same time, that is, if when the lamps are to be turned off, the contacts at *F*, *F*, are broken a little before the cross-connection *E* is made, or, if when the lamps are to be turned on, the cross-connection is broken a little before the connections *F*, *F*, are made, then there will, of course, be arcing, which will introduce a danger from fire. It is necessary that the switch be automatic in its action after it is started on or off, because if it were moved wholly by hand it would sometimes carelessly be left half on and half off and would consequently not only fail to cut off the current completely from the building, but might bring the moving parts of the switch to a point where heating or arcing would be likely to occur and by continuous action cause damage.

The switch should indicate whether it is "on" or "off," so that it shall be known definitely, without regard to anything else, whether the current is turned on the wiring of the building or not. The marking also increases the probability that the switch will be thrown in case of necessity, even by one unfamiliar with its working.

Freedom from moisture is required, so that there will not be leaks between different parts of the switch, or between the parts and the ground. The non-combustible case prevents damage that might be caused by overheating or arcing in a defective switch.

Though the form of switch specifically mentioned in Rule 12 (*b*) can be used only on series circuits, the rule applies generally to all circuits having a pressure of over 300 volts, whether series or multiple. In the case of a multiple circuit, such as a 500-volt motor-circuit, the switch must be of some such form as that shown in Figure 24, where the circuit is broken at once. In this case, it is the pressure that remains constant, and if a cross-connection were made, as in Figure 37, the dynamo would tend to maintain a constant pressure between the two sides of the circuit, and there would consequently be a tremendous flow of current through the connection of low resistance, that would be stopped only by something being melted or burned out.

Snap-switches are not allowed for use on high-potential circuits, because the air-spaces, which make the breaks in the circuit when the switch is off, are very short and the arc that forms upon breaking the circuit is likely to bridge over these spaces, destroy the switch, and endanger property. Snap-switches are sometimes used to extinguish arc lamps by closing a by-path; as if, for instance, one were introduced in *E* in Figure 37. A switch of this kind does not perform the functions of a service-switch, because, although it forms a by-path of low resistance and so causes the lamps to be extinguished, it does not break the connection to the lamps as in Figure 38.

It is required that wires forming a high-potential circuit shall always be in sight, because, with hidden wires, the conditions are always uncertain and the danger of leakage, with its resulting effects, is much more serious with high potential than with low potential. Where wires are exposed to mechanical injury it is sometimes necessary to enclose them.

The kinds of insulated wire that are approved for interior conductors are the same as those given under Rule 10 (*a*), page 80.

The greater danger from leakage from high-potential circuits, is the reason for the requirement that all insulating-tubes, even in dry places, shall be of non-combustible material.

Soldered joints are, of course, quite as necessary for inside work as for that outside. (Page 84.)

### LAMPS AND OTHER DEVICES.

**13. Arc Lamps**—In every case:

*a.* Must be carefully isolated from inflammable material.

*b.* Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

*c.* Must be provided with an *approved* hand-switch, also an automatic switch, that will shunt the current around the carbons should they fail to feed properly.

[Section *c.* The hand-switch to be *approved,* if placed anywhere except on the lamp itself, must comply with requirements for switches on hanger-boards as laid down in Section *g* of Rule 13.]

*d.* Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

*e.* Must be carefully insulated from the circuit in all their exposed parts.

*f.* Must be provided with a wire netting around the globe, and an *approved* spark-arrester above to prevent escape of sparks, melted copper, or carbon, where readily inflammable material is in the vicinity of the lamps. It is recommended that plain carbons, not copper-plated, be used for lamps in such places.

[Section *f.* An *approved* spark-arrester is one which will so close the upper orifice of the globe that it will be impossible for any sparks thrown off by the carbons to escape.]

*g.* Hanger-boards must be so constructed that all wires and current-carrying devices thereon shall be exposed to view and thoroughly insulated by being mounted on a waterproof, non-combustible substance. All switches attached to the same must be so constructed that they shall be automatic in their action, not stopping between points when started, and preventing an arc between points under all circumstances.

*h.* Where hanger-boards are not used, lamps to be hung from insulated supports other than their conductors.

The "arc lamp" makes practical use of the fact that when an air-space is introduced into a circuit, the current in passing through this space heats the ends of the conductors and the resulting gases to a very high degree of incandescence. (Page 33.) Carbon is used as the most suitable material to form the conductors on each side of the air-space. The arc lamp as used is made up principally of regulating apparatus that keeps the arc at the best length by feeding the carbons as they burn away, and maintains steadiness in the light. (Fig. 39.)

The "hand-switch," mentioned in Rule 13 (*c*), is a small switch that will close a by-path round the lamp and thus give a path other than the carbons for the passage of the current. The rules require it so that the lamp may be cut out in case it does not work properly. (Fig. 39.) The "automatic switch" serves the same purpose, but is a part of the regulating apparatus of the lamp itself and cannot be moved by hand if the lamp fail to operate.

The carbons are held in place by "clamps." (Fig. 39.) Should the clamp holding the lower carbon become loose, the carbon, with its intensely hot end, will drop to the floor unless there be a "stop" of some kind to hold it. (Fig. 39.)

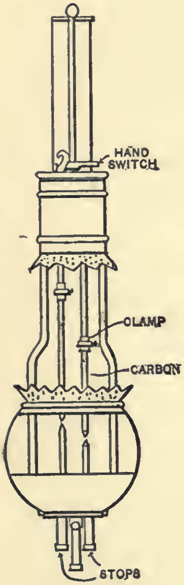

Fig. 39.
Arc Lamp.

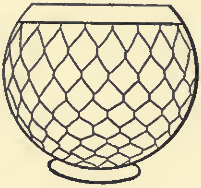

Fig. 40.
Wire Netting for Globes.

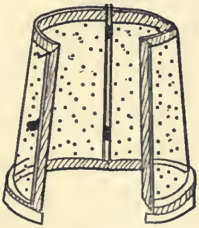

Fig. 41.
Spark-arrester.

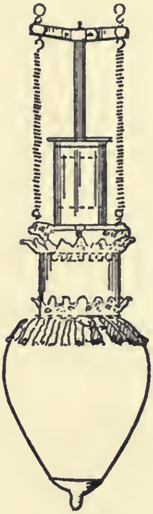

Fig. 42.
Enclosed Arc Lamp.

The "wire netting" required around the globe when the lamp is near inflammable material, is a netting with a mesh about 1¼ inches on a side. In case the globe breaks, the netting will hold all parts in place until a new globe can be provided. (Fig. 40.)

"Spark-arresters" are made in many forms, but they are all designed, as the name indicates, to prevent the small pieces of incandescent material thrown off by the arc from escaping and perhaps setting fire to inflammable material near by. A common form is shown in Figure 41. It consists of a very fine wire screen which fits tight round the globe and encloses the space above. Another form is a flat disk that fits over the top of the globe and has holes for the carbons to pass through. It is now becoming common for indoor lamps to be made in the form shown in Figure 42. The arc is here entirely enclosed by an extension above the globe.

Carbons are usually "plated" because copper is a far better conductor than carbon, and a thin layer of copper on the carbon reduces the resistance and so insures a better contact with the clamps, and thus lessens the waste that comes from driving a current through resistance. This thin layer of copper sometimes flies off in the shape of incandescent particles, so that plain carbons are preferred where inflammable material is near.

"Hanger-boards" are of many forms, but they all have virtually the same characteristics. (Figs. 43, 44.) They are screwed to the ceiling and have conveniences for hanging the lamp so that it may be simply unhooked or disconnected without disturbing the permanent wiring of the circuit. On the board is mounted a switch similar to the arc service-switch, by which the current may be cut off from the lamp and be made to pass only through the connections on the board. This makes it easy at any time to remove a lamp for repairs

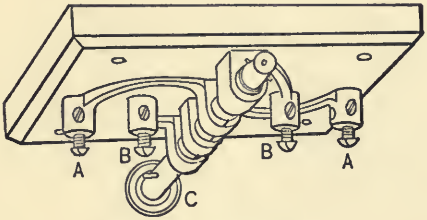

Fig. 43.—Hanger-board.

*C*, Handle for turning current on and off. *BB*, Connections for wires to lamp. *AA*, Connections for line wires.

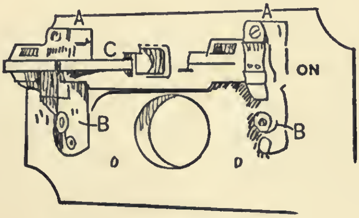

Fig. 44.—Hanger-board.

without shutting off the current from any other lamp. The switch must meet the requirements for the service-switch. Loose connections and imperfect switches cause heating and arcing, and it is necessary that the hanger-board be non-combustible so that nothing will be set on fire in case of defects.

These troubles may be avoided by hanging the lamp direct from insulated supports and bringing the wires to the lamp without going first to a board, but in this case there is no switch to cut off the current from the lamp, and lamps cannot be taken down for repairs with the same facility.

The greatest danger from the arc lamp is just such danger as would come from any centre of great heat, and it will be noted that the rules have for their object the complete isolation of the source of heat. Inflammable material hanging near will, of course, be in danger of catching fire, and the hot particles thrown off by the arc will be apt to burn material beneath if precautions are not taken. Tight globes, closed at the bottom, will catch most of the sparks, but many small ones are carried up by the heated air, and the spark-arresters are necessary to prevent any of these from escaping. Broken globes are an approach to no globes at all, and may allow large sparks to drop from the lamp. The wire netting thus helps to keep the arc entirely enclosed.

**14. Incandescent Lamps in Series Circuits having a Maximum Potential of 300 Volts or over:**

*a.* Must be governed by the same rules as for arc-lights, and each series lamp provided with an *approved* hand spring-switch and automatic cut-out.

*b.* Must have each lamp suspended from a hanger-board by means of a rigid tube.

*c.* No electro-magnetic device for switches and no system of multiple-series or series-multiple lighting will be approved.

*d.* Under no circumstances can series lamps be attached to gas-fixtures.

Incandescent lamps that are made to operate with a comparatively large current are sometimes connected in series circuits. Except that they do not throw off sparks as arc lamps do, there are the same dangers as with other series circuits and the same precautions are to be taken.

The "hand spring-switch" is virtually the same thing as the arc service-switch. It must act in the same way since it is used on a series circuit; that is, it must be made first to form a by-path round the lamp and then to break the connection to the lamp.

The term "automatic cut-out," when used in this connection, means a switch of some kind that will by itself shunt the current round through a by-path when the lamp becomes defective.

The "hanger-board" used with the series incandescent lamp is much the same as that used for arc-lamps, but it is required that the lamp be hung by means of a rigid tube, because incandescent lamps are likely to be moved about and the insulating covering on the conductors would become abraded. This is a more serious matter with the high-potential series circuits than it is with low-potential multiple circuits, not only because of the higher potential, but because if the conductor in a series circuit were to break, a long and destructive arc would be formed.

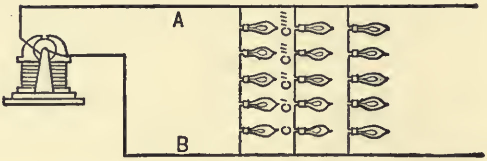

Fig. 45.—Multiple-series System.

"Electro-magnetic devices" for switches are devices that depend for their action upon magnets that become stronger or weaker according to the amount of current that passes round the iron core. The magnetic force works a mechanism that operates the switch. They are objected to because a slight sticking of the movable parts prevents satisfactory working.

A "multiple-series system" is one in which lamps are in different series and these series connected in multiple. (Fig. 45.) There is a constant pressure between the wires $A$ and $B$, so that if at $c$, for instance, a short circuit occurs, that is, if a by-path is formed across the terminals of the lamp, there is less resistance between $A$ and $B$ through this particular series and a larger current will flow. This is likely to burn out the other lamps, $c'$, $c''$, etc., one after the other, with increasing speed and with liability of excessive heating and consequent danger.

A "series-multiple system" is one in which groups of lamps in multiple are connected in series. (Fig. 46.)

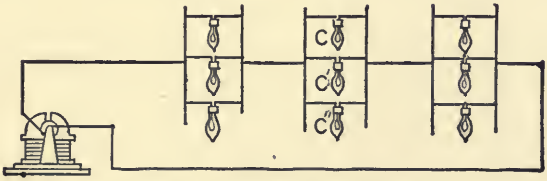

FIG. 46.—Series-multiple System.

The same current must go through each group since all groups are connected in series, and while all is in good order this current will divide properly between the different lamps. If, however, one lamp, say $c$, burns out and thus interrupts the current going through it, the other lamps, $c'$ and $c''$, will have to take more than their share and are likely to burn out with the same attendant dangers as with the multiple-series system.

Gas-pipes are always connected with the ground and if series lamps are attached to the fixtures, the high potential causes great danger of leakage to the pipes, however carefully the insulation is looked after.

The use of incandescent lamps on series circuits is becoming infrequent on account of the dangers and the inconvenience. The system is not suitable to the high degree of subdivision that is the great advantage of the incandescent lamp, for the greater precaution necessary to make the series circuit safe, makes the devices clumsy and rigid, and the portability that adds so much to the usefulness of the incandescent lamp on multiple systems, is thus not possible.

## Class C.

### LOW-POTENTIAL SYSTEMS. — 300 VOLTS OR LESS.

### Outside Conductors.

**15. Outside Overhead Conductors:**

*a.* Must be erected in accordance with the rules for high-potential conductors.

*b.* Must be separated not less than twelve inches, and be provided with an *approved* fusible cut-out that will cut off the entire current as near as possible to the entrance to the building and inside the walls.

[Section *b.* An *approved* fusible cut-out must comply with the sections of Rules 23 and 24 describing fuses and cut-outs. The cut-out required by this section must be placed so as to protect the switch required by Rule 17.]

The conditions to which outside wires are exposed are such that no difference can be made between the construction used for high-potential circuits and that used for low-potential circuits. Though there is less liability of leakage where the electrical pressure is low, there are still all the bad effects when leakage does occur and it is not advisable to attempt less rigid requirements. Sections under Rule 10 accordingly apply also to low-potential circuits.

The fusible cut-out required just inside the walls is similar to that required for motors, shown in connection with Rule 8 (*a*). As with motor-circuits, the cut-out is to be double-pole, and it is to be placed as near as possible to the point where the wires enter the building, so that the whole of the interior wiring may be protected. If it were some distance away from the entrance, cross-connections between the wires at any point lying between the cut-out and the wall would not melt the fuse in the cut-out, because the excessive current would not pass through the fuse.

### 16. Underground Conductors:

*a.* Must be protected against moisture and mechanical injury, and be removed at least two feet from combustible material when brought into a building, but not connected with the interior conductors.

*b.* Must have a switch and a cut-out for each wire between the underground conductors and the interior wiring when the two parts of the wiring are connected.

These switches and fuses must be placed as near as possible to the end of the underground conduit and connected therewith by specially insulated conductors, kept apart not less than two and one-half inches.

[Section *b*. The cut-out required by this section must be placed so as to protect the switch.]

*c*. Must not be so arranged as to shunt the current through a building around any catch-box.

Underground conductors are usually brought into the basement of a building, where it is likely to be damp and where often there is not the best of order, so that it is necessary to take precautions against moisture, and against the abrasion of the wires that would be caused by piling objects round them. There is apt to be greater carelessness when the wires are brought in simply for future use, so there is the additional requirement in this case that they be two feet from combustible material, as this might be set on fire were there to be leakage between the wires.

When the underground conductors are connected with interior wires a cut-out is needed for the reason stated under Rule 15 (*b*). The switch makes it possible to disconnect the interior wires from the main wires whenever necessary. The cut-out in order to protect the switch must be between the switch and the wall, so that if the switch become defective and allow an excessive current to leak between the wires, this current will pass through the fuse and melt it.

A "catch-box" is a box containing a fuse and is in reality only another name for a fuse-box. The term is applied usually only to the fuse receptables in the underground street service. In making the street connections the wires are sometimes improperly connected so that they are not protected by the fuse in the catch-box, but form a by-path, or "shunt," round it through the building.

In Figure 47, for instance, the wiring in the building may first have been connected only with the street mains *A*, no connection being made with the mains *D*. If the mains *A* were supplying all the current and trouble were to occur so that the mains would become connected at *B*, the excessive current that would flow in consequence of the short circuit would melt the fuse in the catch-box *C*. Suppose, however, that more lamps have been put in the building and that the current required is greater than the mains *A* were designed for. In this case there is sometimes another connection made at a point *D*, so that all the current supplying the building will not have to be taken through the mains *A*. Now, if a short circuit occur at *B*, the fuse in the catch-box, *C*, even though it melt, will not prevent the wires from overheating, because the current can come from *D* through the wiring of the building to *B*. There would, of course, be fuses at the service-entrances of the building, but it is bad practice to depend upon building fuses to prevent street damage; for it allows excessive currents to flow unnecessarily through the interior wiring. With such an arrangement as that shown in Figure 47, either all the lamps should be run from one set of mains, or else the wiring in the building should be divided into two distinct parts and one fed from each set of mains.

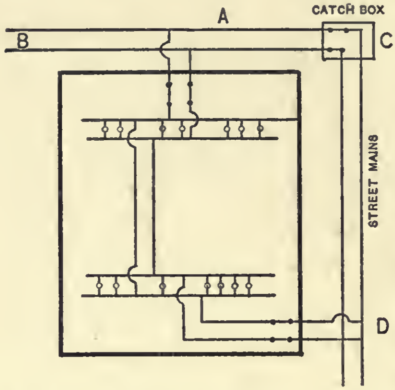

**Fig. 47.—Current shunted through a Building round a Catch-box.**

### INSIDE WIRING.—GENERAL RULES.

**17.** At the entrance of every building there shall be an *approved* switch placed in the service conductors by which the current may be entirely cut off.

[The switch required by this rule to be *approved* must be double-pole, must plainly indicate whether the current is "on" or "off," and must comply with Sections *a, c, d,* and *e* of Rule 26 relating to switches.]

This "service-switch" is placed at the point where the wires enter the building, for the same reasons that such a switch is used with high-potential circuits. (Page 90.) It is usually, however, placed just inside the building instead of outside. It is to be a double-pole switch, that is, one that will break both sides of the circuit as does that used in connection with the motor. (Fig. 24.) With such a switch, current may at any time be cut out of the building entirely, and if in mercantile buildings a practice can be made of turning it "off" every night, there is no question of electrical troubles at a time when no one is about. It is convenient too, when trouble occurs in any part of the installation, for it is not necessary then to wait for the arrival of some one having a knowledge of electrical matters, but the current may be immediately cut off from the interior wires. The base of the switch must be of waterproof and non-combustible material, such as slate or porcelain, to prevent leakage, and damage from arcing. The form may be like that shown in Figure 24 or it may be a double-pole switch similar to that shown in Figure 36.

**18. Conductors:**

*a.* Must have an *approved* insulating covering, and must not be of sizes smaller than No. 14 B. & S., No. 16 B. W. G., or No. 4 E. S. G., except that in conduit installed under

Rule 22, No. 16 B. & S., No. 18 B. W. G., or No. 4 E. S. G. may be used.

[Section *a*. In so-called "concealed" wiring, moulding and conduit work, *and* in places liable to be exposed to dampness, the insulating covering of the wire, to be *approved*, must be solid, at least three-sixty-fourths of an inch in thickness, and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahr., and three days' submersion in lime-water, with a current of 550 volts, and after three minutes' electrification.

(See List of Wires, page 80.)

For work which is *entirely* exposed to view throughout the whole interior circuits, and not liable to be exposed to dampness, a wire with an insulating covering that will not support combustion, will resist abrasion, is at least one-sixteenth of an inch in thickness, and thoroughly impregnated with a moisture repellent, will be approved.]

It will be noticed that the insulating covering of wires used for low-potential wiring is to be the same as that required for high-potential wiring, except where the work "is entirely exposed to view throughout the whole interior circuits, and not liable to be exposed to dampness." For this excepted work the better grades of the wire termed "Weatherproof" meet the requirements. So-called "Underwriters'" wire is not allowed under any conditions.

No. 14 B. & S. (Brown & Sharpe Gauge), No. 16 B. W. G. (Birmingham Wire Gauge), and No. 4 E. S. G. (Edison Standard Gauge) are all of nearly the same size, about one-sixteenth of an inch in diameter. The B. & S. gauge is the gauge commonly used in this country. No wire smaller than No. 14 B. & S. gauge is allowed, except in conduit, because it is otherwise not strong enough mechanically. Small wires strung on ceilings may easily become stretched and thus not only be, by the displacement, more liable to further damage, but the sectional area may by this stretching be so reduced that the wire will heat when the normal current passes. There is also less probability that very small wires will be properly protected by the fuses.

*b.* Must be protected when passing through FLOORS; or through walls, partitions, timbers, etc., in places liable to be exposed to dampness by waterproof, non-combustible insulating-tubes, such as glass or porcelain.

Must be protected when passing through walls, partitions, timbers, etc., in places not liable to be exposed to dampness by *approved* insulating bushings specially made for the purpose.

[Section *b.* Second paragraph. Except for FLOORS, *and* for places liable to be exposed to dampness, Glass, Porcelain, *metal-sheathed* Interior Conduit and Vulca Tube, when made especially for bushings, will be *approved. The two last named will not be approved if cut from the usual lengths of tube made for conduit work, nor when made without a head or flange on one end.*]

*c.* Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material which they may cross (except high-potential conductors) by some continuous and firmly fixed non-conductor creating a separation of at least one inch. Deviations from this rule may sometimes be allowed by special permission.

*d.* Must be so placed in crossing high-potential conductors that there shall be a space of at least one foot at all points between the high and low tension conductors.

*e.* Must be so placed in wet places that an air-space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run *over* all pipes upon which condensed moisture is likely to gather, or which by leaking might cause trouble on a circuit.

*f.* Must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

[Section *f.* All joints must be soldered, even if made with the McIntyre or any other patent splicing device. This ruling applies to joint and splices in all classes of wiring covered by these rules.]

Rule 18 (*b*) is not always properly read. Non-combustible tubes are always required in floors. In walls, partitions, etc., they are required only in places liable to be exposed to moisture. (Pages 61, 89.) The only tubes, in addition to non-combustible tubes, thus far approved for dry places are the kinds mentioned under Rule 18 (*b*).

Rule 18 (*c*) is made to insure proper insulation of the wiring from the ground. (Page 59.) The wire, if not rigidly fastened so that it will be held away from conducting material, may, by being struck or by sagging, come into contact with this material. The aim of the rule is to keep the wire away from conducting material of any kind, but the greatest danger comes from pipes because they are directly connected with the earth. Construction similar to that shown in Figure 48 will insure the separation. Conductors that are not connected directly with the earth, such as a nail driven into a beam, appear sometimes to be harmless, but it should be remembered that whereas a slight contact between the wire and the beam itself might result in virtually no leakage, a driven nail presents a comparatively large surface to the wood, and if the wood were at all moist, contact with the nail might result in considerable leakage and cause dangerous sparking.

Construction is allowed with low-potential systems that is not allowed with high-potential systems, and Rule 18 (*d*) is made so that there can be no possibility of contact between the two.

An air-space is required where wires cross pipes in damp places, because there would be danger of leakage over the surface of any material between the two, if this material were damp. If wires are run under pipes on which moisture gathers, the moisture may cause a cross-connection between the pipe and the wires. (Fig. 49.)

All joints are to be soldered, as they are with high-potential circuits. (Page 84.)

### SPECIAL RULES.

**19. Wiring not Encased in Moulding or Approved Conduit:**

*a.* Must be supported wholly on non-combustible insulators, constructed so as to prevent the insulating coverings of the wire from coming in contact with other substances than the insulating supports.

*b.* Must be so arranged that wires of opposite polarity, with a difference of potential of 150 volts or less, will be kept apart at least two and one-half inches.

*c.* Must have the above distance increased proportionately where a higher voltage is used.

*d.* Must not be laid in plaster, cement, or similar finish.

*e.* Must never be fastened with staples.

"Moulding" is made in two pieces so as wholly to encase the wire, and thus acts as a protection to the insulating covering. (Fig. 50.)

"Conduit" is tubing that serves as a raceway or channel for wires, the building being piped with it as if for water or gas. The wire is then run inside, so that the whole wiring installation is isolated and protected. (Pages 51, 122.)

The two wires of a circuit are wires of "opposite polarity." The convention has been adopted of calling the side of the dynamo from which the current is supposed to start, the positive or + pole, and the side to which the current returns, the negative or – pole. The wires leading from the dynamo are thus spoken of as being of opposite polarity, one being the positive pole of the circuit and the other the negative pole.

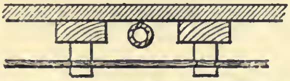

**Fig. 48.—Showing Wire held away from a Pipe which it crosses.**

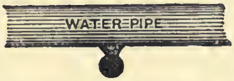

**Fig. 49.—Condensed Moisture forming Connection between Pipe and Wire.**

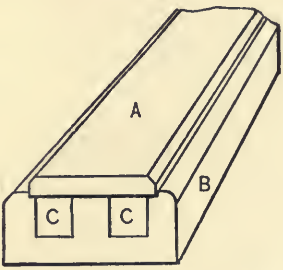

**Fig. 50.—Moulding. *A*, Capping. *B*, Backing. *C*, Grooves for wire.**

It will be noticed that there are only three approved ways of running wires: in moulding, in conduit, and wholly on non-combustible insulators. The intention of Rule 19 (*a*) is to prevent possibility of leaks, and also to have the wire in contact only with non-combustible material so that no harm will come in case the wire be excessively heated by a heavy current. While everything is perfectly dry there is no danger of leakage, and it was formerly the practice to fasten the wire directly against wooden ceilings; but it is not known when conditions may change by the spilling of water, or the leaking of roofs, and moreover the allowing of a poorer construction in some cases, leads to the adoption of this construction in other cases when it is not at all suitable. To use the construction everywhere that is everywhere good, costs but little more and is much safer and more satisfactory.

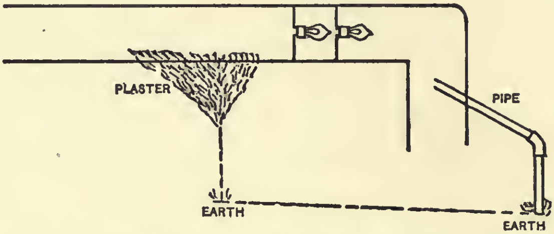

**Fig. 51. Wires grounded through Moist Plaster and Pipe, thus forming a Cross-connection between the Two Sides of the Circuit.**

A very short air-space is sufficient insulation with such pressures as are used in practice, but the distances between wires, specified in Rule 19 (*b*), are required because wires that become slightly loose are apt to come together unless they were originally some distance apart. Moreover, leakage may take place over damp surfaces, and it is wiser not to make the distances too short.

Rule 19 (*a*) covers the construction mentioned in Rule 19 (*d*), but it is brought out specifically in the latter rule to give greater prominence, and because it might be thought that plaster and cement are non-combustible insulating materials. On the contrary, they are fair conductors when moist, and moreover they act on the insulating covering of the wire, finally destroying the insulating properties. Even though no harm were done at the point where the leakage takes place in the plaster, such leakage might "ground" one side of the circuit and thus make possible at another point, as at a gas-fixture, a short circuit that would burn through the pipe and ignite the gas. (Fig. 51.)

FIG. 52. Metal Staple.

The ordinary staple (Fig. 52) is of course a direct violation of Rule 19 (*a*), but staples are made that are insulated and that keep the wire out of contact with other substances. (Fig. 53.) These are also prohibited, however, for in fastening the wire with them they are driven into the wood and are liable to injure the insulating covering of the wire.

### IN UNFINISHED LOFTS, BETWEEN FLOOR AND CEILINGS, IN PARTITIONS AND OTHER CONCEALED PLACES.

*f.* Must have at least one inch clear air-space surrounding them.

*g.* Must be at least ten inches apart when possible, and should be run singly on separate timbers or studding.

*h.* Wires run as above immediately under roofs, in proximity to water-tanks or pipes, will be considered as exposed to moisture.

*i.* When from the nature of the case it is impossible to place concealed wire on non-combustible insulating supports of glass or porcelain, the wires may be fished on the loop system, if encased throughout in *approved* continuous flexible tubing or conduit.

*j.* Wires must not be fished for any great distance, and only in places where the Inspector can satisfy himself that the above rules have been complied with.

*k.* Twin wires must never be employed in this class of concealed work.

Wires are said to be "fished" when they are started in at one end of a concealed space and then, so that they may be pulled through, are felt for, or "fished" for, from the other end, with a hooked wire or other contrivance. Such a procedure leaves doubt as to the condition in the space between the entrance and the exit, for the insulation may be scraped, or the wires may rest on pipes. Figure 54 illustrates wires "fished on the loop system." The idea of the rule allowing this method, is to provide for construction in old buildings where it is not possible to conceal the wire by means of such construction as would be employed in new buildings. According to the rule, wire in a flexible conduit may be fished just as the wire alone would be fished, and is threaded-in through concealed spaces so that it makes the tour, so to speak, of all points where lamps are to be connected. The object of confining this construction to the loop system is to prevent joints being made in concealed spaces. The construction is intended principally for installations in which only a small number of lamps are used.

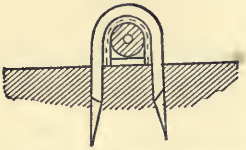

FIG. 53.—Insulating-staple.

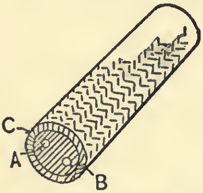

FIG. 55.—Twin wire. *A*, Copper wires. *B*, Rubber insulation separating and surrounding copper wires. *C*, Braided outer covering.

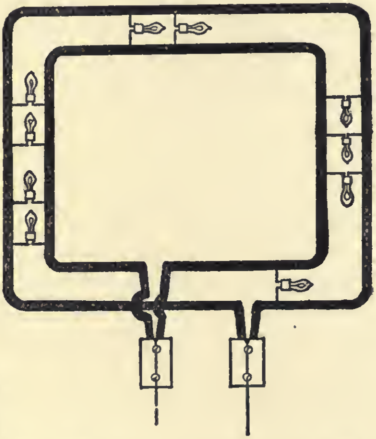

FIG. 54.—Flexible Conduit, run on the Loop System.

"Twin wires" are two wires laid together and surrounded and separated by insulating material, so that the whole forms one piece. The wires are separate conductors and form the two sides of the circuit. (Fig. 55.) Of course any jamming or bruising of this piece is apt to bring the two sides of the circuit into contact and thus form a short circuit.

In concealed spaces more exacting requirements are necessary than with open work, because the construction cannot be easily examined, any defect is more serious, and there is more temptation to the workmen to slight the work. Compliance with Rule 19 (*h*) requires non-combustible insulating-tubes to be used where wires pass through walls, wood, etc., and allows only such wire and insulation as that specified for places exposed to moisture.

**20. Mouldings:**

*a.* Must never be used in concealed work or in damp places.

*b.* Must have at least two coats of waterproof paint or be impregnated with a moisture repellent.

*c.* Must be made of two pieces, a backing and capping, so constructed as to thoroughly encase the wire and maintain a distance of one-half inch between conductors of opposite polarity and afford suitable protection from abrasion.

Moulding is simply a protection against mechanical injury, and in damp places may be even worse than nothing about the wire, since an air-space is an insulator while wet wood is a fair conductor. In dry places, however, moulding guards against mechanical injury to the insulating covering of the wire, and is a sufficient insulator itself. Saturating the moulding with a substance that will prevent the absorption of moisture guards against the danger of leakage in case of accidental conditions. The moulding is of course an additional danger in case of overheated wires, and though its use is allowed in a limited way it is not thought to afford first-class construction. (Fig. 50.)

**21. Special Wiring:**

In breweries, packing-houses, stables, dye-houses, paper and pulp mills, or other buildings specially liable to moisture or acid, or other fumes liable to injure the wires or insulation, except where used for pendants, conductors —

*a.* Must be separated at least six inches.

*b.* Must be provided with an *approved* waterproof covering.

[Section *b.* The insulating covering of the wire to be *approved* under this section must be solid, at least three-sixty-fourths of an inch in thickness and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahr., and three days' submersion in lime-water, with a current of 550 volts after three minutes' electrification, and must *also* withstand a satisfactory test against such chemical compounds or mixtures as it will be liable to be subjected to in the risk under consideration.]

*c.* Must be carefully put up.

*d.* Must be supported by glass or porcelain insulators. No switches or fusible cut-outs will be allowed where exposed to inflammable gases or dust, or to flyings of combustible material.

*e.* Must be protected when passing through floors, walls, partitions, timbers, etc., by waterproof, non-combustible, insulating-tubes, such as glass or porcelain.

The requirements stated under Rule 21 are, it will be noticed, simply more exacting than those for work subject to ordinary conditions. Rule 21 (*d*) meets a special condition that sometimes exists, and is made necessary because the action of switches and the melting of fuses cause an arc of short duration that might ignite gases or finely divided dust. The wire for these special places must stand a more severe test, and the list of approved wires given on page 80 is not necessarily correct for all these special conditions.

### **22. Interior Conduits:**

[The object of a tube or conduit is to facilitate the insertion or extraction of the conductors, to protect them from mechanical injury, and, so far as possible, from moisture. Tubes or conduits are to be considered merely as raceways, and are not to be relied on for insulation between wire and wire, or between the wire and the ground.

The American Circular Loom Company Tube, the *brass-sheathed* and the *iron-armoured* tubes made by the Interior Conduit and Insulation Company, and the Vulca Tube are approved for the class of work called for in this rule.

NOTE.—The use of two *Standard* wires (see page 80), either separate or twin conductor, in a straight conduit installation is approved in the *iron-armoured* conduit of the Interior Conduit and Insulation Company, but not in any of the other approved conduits. (See Rule 22 *e.*)]

*a.* Must be continuous from one junction-box to another, or to fixtures, and must be of material that will resist the fusion of the wire or wires they contain without igniting the conduit.

*b.* Must not be of such material or construction that the insulation of the conductor will ultimately be injured or destroyed by the elements of the composition.

*c.* Must be first installed as a complete conduit system, without conductors, strings, or anything for the purpose of drawing in the conductors, and the conductors then to be pushed or fished in. The conductors must not be placed in position until all mechanical work on the building has been, as far as possible, completed.

*d.* Must not be so placed as to be subject to mechanical injury by saws, chisels, or nails.

*e.* Must not be supplied with a twin conductor, or two separate conductors in a single tube. (See foregoing note.)

*f. Must have all ends closed* with good adhesive material, either at junction-boxes or elsewhere, whether such ends are concealed or exposed. Joints must be made airtight and moisture-proof.

*g.* Conduits must extend at least one inch beyond the finished surface of walls or ceilings until the mortar or other similar material be entirely dry, when the projection may be reduced to half an inch.

A "junction-box" (Fig. 56) is a box made of material similar to that composing the conduit with which it is used, and it is placed where connections are to be made, as, for instance, where a tap wire joins a branch wire or where a branch wire joins a main wire. In these boxes the tubes making up the conduit system end, and from these points all wires are inserted or withdrawn. The use of the junction-box makes easy the connection of the wires, it brings these connections to an accessible place, and it provides a receptacle for the fuse-blocks. When these boxes are used it is unnecessary to have concealed joints in the wires and it is possible always to remove lengths of wire that may become defective or that will be too small for an increased number of lights.

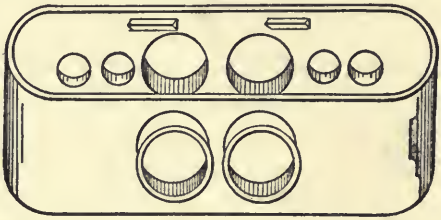

**Fig. 56.—One form of Junction-box; shown without cover.**

Since conduit is allowed in all sorts of places, it should not be of such material that it would burn upon the fusing of the wire. If the wire be properly protected by fuses, it can never overheat sufficiently to melt; but the safety of the construction obviously should not depend upon the carefulness of the men who place the fuses.

As the conduit is not depended upon for insulation, it is doubly important that there be nothing in its composition that will injure the insulation on the wire.

The virtues of the conduit consist in its being a complete protection to the insulation on the wire, entirely enclosing it at all points, and in its affording a smooth and ample raceway for the insertion and extraction of the wires. If conduits were allowed to be installed with the wires inside, there would not be the same necessity to the workman of joining the tubes accurately that there is when the wires must be afterwards inserted, and many installations would, through carelessness, be little better than plain installations of fished wire, with lengths of tube strung along the wire as suited the convenience of the workman. Even if it were allowable to lay strings in the tubes at the time they are placed, so that the wires might be pulled in afterward by means of the strings, there would be danger of abrading the insulation on the wire, because it would then be possible, on account of the force that could be applied, to pull wires through tubes that are too small, or in which there are obstructions that would tear the insulation. There would be lost, too, all advantage that comes from being able to remove and replace wires with facility. By requiring the conduit to be first installed as a complete system and the wire to be then pushed in, there is assurance that the joints in the tube are well made — for otherwise the wire would catch — and that there are no nails driven through the tube, or obstructions in it, for in these cases the wire could not be forced through.

If conductors are inserted before the mechanical work on the building is completed, any damage to the installation through crushing, cuts, or punctures, not only injures the tubing as a mechanical protection, but it is apt to injure the insulation on the wire at the same place. If the wire is inserted after the work on the building is completed, these damages are likely to be discovered when an attempt is made to insert the wire, and even though the wire slip through easily and the defect in the tubing is not discovered, there is at least the surety that the electrical insulation on the wire is intact.

If a tube containing a twin wire (Fig. 55) or two separate wires, were pierced by a nail and a short circuit thus caused, or if from any other cause an arc were to form in the conduit, there would be danger of the conduit's igniting before the protecting fuse could melt. With the iron-armoured conduit there is very little liability of such short circuits' forming, because the iron armour is a thick iron pipe like a gas-pipe, and is an effectual protection against nails. Even though an arc form within the conduit, harm could hardly be done, since the fuse protecting the circuit would melt before the iron would be burned through.

Rule 22 (*f*) is made because it is wished to have the conduit as free from moisture as possible, and by having the ends closed and the joints air-tight there is less liability of the gathering of condensed moisture.

### 23. Double-pole Safety Cut-outs:

*a.* Must be in plain sight or enclosed in an *approved* box, readily accessible.

[Section *a.* To be *approved,* boxes must be constructed, and cut-outs arranged, whether in a box or not, so as to obviate any danger of the melted fuse metal's coming in contact with any substance which might be ignited thereby.]

*b.* Must be placed at every point where a change is made in the size of the wire (unless the cut-out in the larger wire will protect the smaller).

*c.* Must be supported on bases of non-combustible, insulating, moisture-proof material.

*d.* Must be supplied with a plug (or other device for enclosing the fusible strip or wire) made of non-combustible and moisture-proof material, and so constructed that an arc cannot be maintained across its terminals by the fusing of the metal.

*e.* Must be so placed that on any combination fixture no group of lamps requiring a current of six ampères or more shall be ultimately dependent upon one cut-out. Special permission may be given *in writing* by the Inspector for departure from this rule in case of large chandeliers.

*f.* All cut-out blocks must be stamped with their *maximum* safe-carrying capacity in ampères.

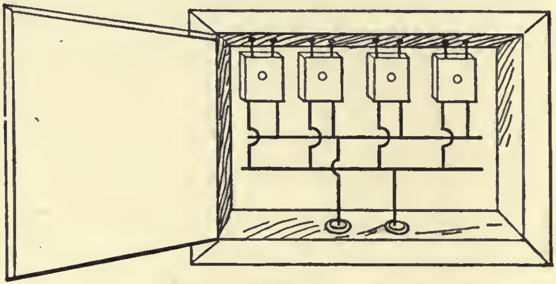

Fig. 57.—Fuse Closet.

It is required that cut-outs or fuse-blocks be in plain sight, because when the fuse melts there is an arc for at least a short time and it is obviously dangerous to have this take place in a concealed place, where there possibly may be inflammable material. Besides this it is unlikely that the fuses will be properly inspected unless they can easily be seen. Where there are several cut-outs grouped, it is more convenient to have them enclosed in a box built flush with the wall. The best boxes are made entirely of non-combustible material, but they are usually made of wood, lined throughout with asbestos board. (Fig. 57.) (See page 41.)

Where branches lead off from main wires, care must be taken that fuses be provided to protect the branches. Thus, in Figure 58, suppose a branch to be taken off at *A*. On the wires *BB* is a motor, and on the wires *AA* are 5 lamps. Suppose the motor to require 25 ampères. Then the fuses at *C* must have a carrying capacity of at least 25 ampères or they will melt when the motor operates. But suppose the wires *AA* to be No. 14 B. & S. gauge, which is large enough to carry the current required for the 5 lamps that the wires supply, but which would overheat before the fuses at *C* could melt, in case there were a short circuit. It is consequently necessary to have smaller fuses at *A*, where the size of

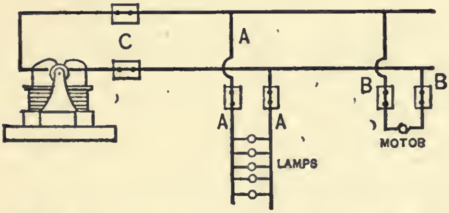

FIG. 58. — Illustrating Use of Branch Fuses.

wire changes, so that the carrying capacity of these No. 14 wires will not be exceeded. If there were no motor or lamps on the wires *BB*, then there would be no need of fuses at the point *A*, because a small fuse that would protect the wires *AA* could be put in the cut-out at *C*.

The bases of cut-outs must be non-combustible, because otherwise they are liable to ignite from the heat of the arc that forms when a fuse melts ; they must be of insulating material, because otherwise there would be constant leakage; they must be waterproof, or dampness will cause leakage.

When fuses melt, the arc that is formed sometimes melts off particles of the copper or brass to which the fuse is attached, and if this molten metal flies into inflammable material it may be ignited. For this reason it is required that the fusible metal be entirely enclosed by non-combustible material, as it would be, for instance, in a cut-out like that shown in Figure 22 where there is a porcelain cover. Figures 59 and 60 give two views of a "plug cut-out." The fusible metal is soldered to brass terminals set in glass, and a brass cap screws over the top. The whole plug screws into a special cut-out base.

If the fuse be too short, the arc formed by the melting of the fuse will continue between the terminals to which the fuse is attached, and will give out intense heat just as an arc lamp does. It is consequently of great importance that the length of fuse be enough to insure an arc of short duration. The electrical pressure, and the current at the time the fuse melts, both determine the distance the arc can hold over; but as there is always a liability, and even a probability, that the fuse will melt because of a short circuit, and consequently from a very heavy current, the correct length of fuse must not be judged by the smallest current that will fuse it. If arcing is to be prevented, the length of fuse metal for 50 volts should be about $\frac{3}{4}$ inch, the length for 110 volts about 1 inch, for 220 volts about $1\frac{1}{2}$ inches, and for 500 volts not less than 4 inches.

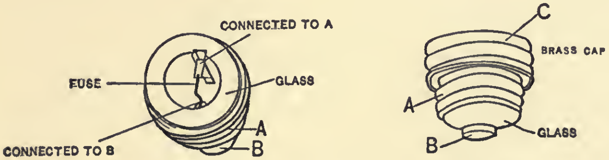

Fig. 59. Fig. 60.

Plug Cut-out.

A "combination fixture" is one that is arranged so that either gas or electric lights may be used. If a large number of lamps were dependent upon one fuse, or rather, if one lamp were dependent upon a fuse large enough to carry the current for many lamps, then a short circuit in one of the lamps or its receptacle, might cause a vicious arc that would burn through the gas-pipe and do considerable damage before the fuse could melt. Even though there be no wire in circuit small enough to require a five-ampère fuse, lamps on combination fixtures should nevertheless be arranged so that no lamp will be dependent upon a fuse larger than this.

Cut-outs should be stamped with their maximum carrying capacity so that there will be no excuse for overloading them. The parts that carry current are naturally made no larger than necessary, and an excessive current would dangerously overheat them.

### 24. Safety Fuses:

*a.* Must all be stamped or otherwise marked with the number of ampères they will carry indefinitely without melting.

*b.* Must have fusible wires or strips (where the plug or equivalent device is not used), with contact surfaces or tips of harder metal, soldered or otherwise, having perfect electrical connection with the fusible part of the strip.

*c.* Must all be so proportioned to the conductors they are intended to protect that they will melt before the maximum safe-carrying capacity of the wire is exceeded.

The largest number of ampères that a fuse will carry for an indefinite time without melting, is its carrying capacity. It is better to mark the fuse with its carrying capacity than with its fusing-point, because the amount of current that the conductors are to carry is determined by their size, and it is only necessary to choose a fuse with the same carrying capacity that the wire has. If the fuse were marked with its fusing-point, a careless or ignorant person might allow altogether too much margin in choosing the size of fuse for a given case. It is important that the fuse itself be marked, not only so that one will know definitely what is used, but because when the fuse melts it is then known what size is required properly to replace it.

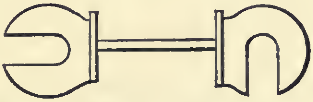

Fig. 61.—Fuse with Tips of Hard Metal.—Fuse-link or Safety-catch.

Figure 61 shows a fuse having tips of copper soldered to the fuse-wire. These are called "fuse-links" or "safety-catches." Fuse-metal being soft and inelastic cannot be properly fastened under the head of the binding screws in the cut-out. It is apt gradually to work loose, thus making a poor contact that is a frequent cause of overheating in the cut-out. The copper tips furnish a true, hard, and elastic terminal that can be securely clamped. Moreover, these fuse-links with tips of harder metal are more accurate as regards their fusing-point than is fuse-wire alone. A fuse-wire of a given diameter will have different fusing-points for different lengths of fuse; for when the fuse is very short, the metal to which it is attached conducts the heat away from the fuse so fast that a large current is necessary to generate heat fast enough to melt it. When the fuse is long, the heat is not taken away from the fuse-metal so fast, and a smaller current will melt it. With fuse-links, however, the length of fuse-metal is fixed because it is soldered to the copper terminals, and the manufacturer is careful to choose a size that will have the proper fusing-point. Figure 62 illustrates this change in fusing-point with the change in length of fuse. With the size fuse-wire for which this curve is true, it will be noticed that when the

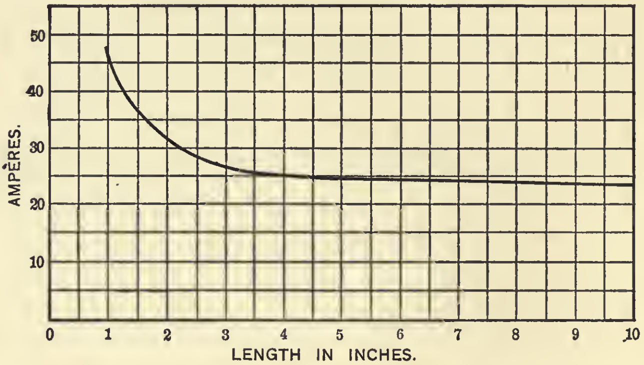

FIG. 62.—Showing Different Fusing-points for Different Lengths of the Same Fuse-wire.

fuse is 5 inches or longer, the fusing-point is very close to 24 ampères, but that when the fuse is 1 inch long, for instance, the fusing-point is 45 ampères.

If the fuse is to protect the wire, it is obvious that it must melt before the carrying capacity of the wire is exceeded. It is, of course, not possible for the fuse to heat to the melting-point instantly when an excessive current flows, but as the wire cannot instantly heat to a dangerous temperature either, the fuse properly proportioned is a good protection against this particular kind of danger.

Setting fire to combustible material by direct contact is not the only danger to be apprehended from overheated wires. The insulating properties of the covering are injured by excessive heat, and if the wires become hot and are exposed to ground connections, leakage troubles arise. The carrying capacities given in the following table are supposed, however, to be low enough to prevent this.

### 25. Table of Capacity of Wires:

It must be clearly understood that the size of the fuse depends upon the size of the smallest conductor it protects, and not upon the amount of current to be used on the circuit. Below is a table showing the safe-carrying capacity of conductors of different sizes in Brown & Sharpe gauge, which must be followed in the placing of interior conductors:

|  | TABLE A. | TABLE B. |
|---|---|---|
|  | Concealed Work. | Open Work. |
| B. & S. G. | Ampères. | Ampères. |
| 0000 | 218 | 312 |
| 000 | 181 | 262 |
| 00 | 150 | 220 |
| 0 | 125 | 185 |
| 1 | 105 | 156 |
| 2 | 88 | 131 |
| 3 | 75 | 110 |
| 4 | 63 | 92 |
| 5 | 53 | 77 |
| 6 | 45 | 65 |
| 8 | 33 | 46 |
| 10 | 25 | 32 |
| 12 | 17 | 23 |
| 14 | 12 | 16 |
| 16 | 6 | 8 |
| 18 | 3 | 5 |

NOTE. — By "open work" is meant construction which admits of all parts of the surface of the insulating covering of the wire being surrounded by *free* air. The carrying capacity of 16 and 18 wire is given, but no wire smaller than 14 is to be used except as allowed under Rules 18 (*a*) and 27 (*d*).

The size of wire that is chosen for a circuit is determined by the amount of current it has to carry, and the fuse is determined by the size of wire. If the fuse be always chosen with regard to the size of wire only, the wire cannot be dangerously small and still be used, because when a current above its carrying capacity is sent through it, the fuse will melt.

**26. Switches:**

*a.* Must be mounted on moisture-proof and non-combustible bases, such as slate or porcelain.

*b.* Must be double-pole when the circuits which they control supply more than six 16 candle-power lamps, or their equivalent.

*c.* Must have a firm and secure contact; must make and break readily, and not stop when motion has once been imparted by the handle.

*d.* Must have carrying capacity sufficient to prevent heating.

*e.* Must be placed in dry, accessible places, and be grouped as far as possible, being mounted — when practicable — upon slate or equally non-combustible back boards. Jack-knife switches, whether provided with friction or spring stops, must be so placed that gravity will tend to open rather than close the switch.

If switches are not mounted on waterproof and non-combustible bases, arcing and heating caused by accidental conditions, will be apt to set the base on fire.

A single-pole switch draws a longer arc than a double-pole switch draws, because the single-pole switch breaks the circuit in only half as many places; and moreover, since it is on only one side of the circuit, it does not break all connection with the wire beyond the switch. (Page 76.) For these reasons the single-pole switch is thought suitable only for small tap circuits and its use is limited to branches having on them not more than six 16 candle-power lamps. The making of a connection that completes a circuit, and the breaking of a connection that interrupts a circuit, are spoken of as the "make and break."

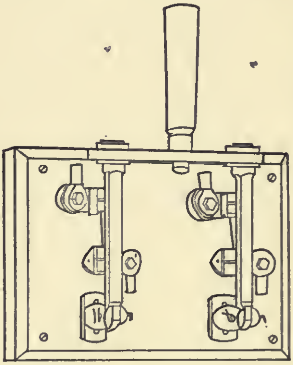

Fig. 63. — Jack-knife Switch.

Rule 26 (*c*) is made to provide against the arcing in the switch that would be caused by poor construction. If the parts of a switch that conduct the current are too small, or if the surfaces that come together do not make sufficient connection, the switch will heat just as a wire that is too small will heat. Resistance is introduced and wherever current is forced through resistance there is heat.

The "jack-knife switch" is shown in Figure 63. It will be seen that if the switch were mounted so that it would be closed by moving the handle down, it would be closed by anything accidentally falling on it, or possibly by a jarring of the supports. This unintentional closing might cause a short circuit somewhere, as at a motor, for instance. Stops of some kind, either springs or friction arrangements, are usually provided, but they are not always trustworthy, and it is just as easy and as convenient to mount the switch so that it tends to fall open rather than shut.

### 27. Fixture Work:

*a.* In all cases where conductors are concealed within or attached to gas-fixtures the latter must be insulated from the gas-pipe system of the building by means of *approved* joints. The insulating material used in such joints must be of a substance not affected by gas and that will not shrink or crack by variation in temperature. Insulating-joints with soft rubber in their construction will not be approved.

[Section *a.* Insulating-joints to be *approved* must be entirely made of material that will resist the action of illuminating gases and will not give way or soften under the heat of an ordinary gas-flame. They shall be so arranged that a deposit of moisture will not destroy the insulating effect and shall have an insulating resistance of 250,000 ohms between the gas-pipe attachments, and be sufficiently strong to resist the strain they will be liable to in attachment.]

*b.* Supply-conductors and especially the splices to fixture wires, must be kept clear of the grounded part of gas-pipes, and where shells are used the latter must be constructed in a manner affording sufficient area to allow this requirement.

*c.* When fixtures are wired outside, the conductors must be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

*d.* All conductors for fixture-work must have a waterproof insulation that is durable and not easily abraded, and must not in any case be smaller than No. 18 B. & S., No. 20 B. W. G., No. 2 E. S. G.

*e.* All burrs or fins must be removed before the conductors are drawn into a fixture.

*f.* The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

*g.* No combination fixture in which the conductors are concealed in a space less than one-fourth inch between the inside pipe and the outside casing will be approved.

*h.* Each fixture must be tested for "contacts" between conductors and fixtures, for "short circuits," and for ground-connections before the fixture is connected to its supply-conductors.

*i.* Ceiling-blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate must be surrounded with hard-rubber tubing.

There are numerous opportunities for trouble in the wiring about gas-fixtures. The fixtures themselves are of metal, and the wires must necessarily be run in confined spaces and close to this metal; the gas-pipe system forms a conducting network throughout a building and has good connection with the earth; thus there is not only opportunity for "grounds," but any defect that causes an arc is apt to burn through the gas-pipe, ignite the gas and immediately start a blaze.

The greatest danger of accidental connection is between wires and the fixtures, and consequently it is required that the fixture be joined to the gas-pipe system by means of an "insulating-joint." Figure 64 shows one form. This insulating-joint allows the gas to pass through, but insulates the fixture so that in case a wire becomes electrically connected with it, a connection somewhere else in the building, such as between the other wire of the circuit and another fixture, will not cause a flow of current through the gas-pipe system. Were this to occur there would be a short circuit with a heavy flow of current and there would be formed at the points of contact, an arc that would quickly burn through the pipe. By insulating the fixture entirely, to cause a short circuit it is necessary that two accidental connections on the same

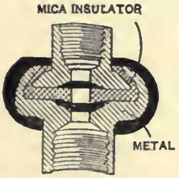

Fig. 64.—Section of Insulating-joint.

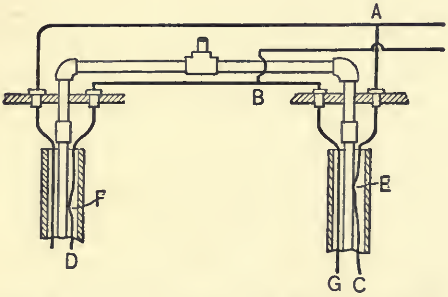

Fig. 65.—Showing Circuits on Fixtures not provided with Insulating-joints.

fixture occur, and these two connections must be on opposite sides of the circuit — one connection for each wire, or pole.

Figure 65 illustrates the effect of having no insulating-joints. If, for instance, the wire *C* coming from the *A* wire of the circuit were to have connection with the fixture at *E*, and the wire *D* coming from the *B* wire of the circuit were to have connection with any one of the numerous fixtures of the building as at *F*, then a heavy current would immediately flow from *A* through *C*, thence to the fixture and gas-pipe at *E*, through the gas-pipe system and other fixture to *F*, through the fixture wire *D* to *B*, the other side of the circuit. If there were insulating-joints in these gas-fixtures, as in Figure 66, two connections like those supposed could not cause a short circuit, because there would be no path from *F* to *E* through the gas-pipe, since the current could not pass the insulation in the joints. To cause trouble it would be necessary to have not only the connection at *E*, for instance, but another connection with the same fixture somewhere along the wire *G*. The insulating-joints, by cutting off each fixture by itself, reduce greatly the probability of trouble.

Rule 27 (*a*) and the accompanying note specify in detail the standard that must be reached by an insulating-joint, and incidently suggest the many ways in which a joint may be dangerously defective. The underwriters furnish lists of the insulating-joints that have been tested and approved.

There is an opportunity for careless work at the tops of fixtures where the "supply-conductors" (Fig. 66) come through the ceiling to be attached to the "fixture wires." These supply-wires are brought down close to the gas-pipe to which the fixture is attached and should, as Rule 27 (*b*) requires, be carefully kept away from the part of the gas-pipe system that is connected with the ground. "Shells" (Fig. 66) are ordinarily used, and as these cover up the work there is less inducement for the workmen to do the work carefully, even when the shell is large enough to take the wires and splices without crowding.

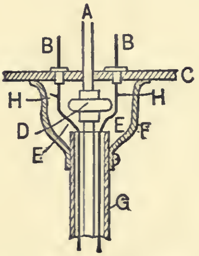

FIG. 66.—*A*, Gas-pipe. *B*, Supply-conductors. *C*, Ceiling. *D*, Insulating-joint. *E*, Fixture wires. *F*, Shell. *G*, Outer Casing of Fixture. *H*, Splices.

"Burrs" and "fins" are the sharp edges left when the sheet-metal composing the fixtures is cut. These, if left, will injure the insulating covering of the wire when it is drawn over them.

The upper ends of fixtures are usually "sealed" by wrapping tape (page 89) about them until they are virtually air-tight.

The gas-pipe running down through the fixtures is surrounded by a larger tube or "casing," and between these the electric wires are run. When this space is too small for the wires to be drawn through easily, the insulation is apt to become abraded.

The testing required in Rule 27 (*h*) can of course be satisfactorily done only by those familiar with the work.

Fixtures are often fastened against a block that is attached to the ceiling. If this "ceiling-block" itself is not of a material suitable for bushings, a regular insulating bushing, such as would be proper through the ceiling, should be used.

### 28. Arc Lights on Low-potential Circuits:

*a.* Must be supplied by branch conductors not smaller than No. 12 B. & S. gauge.

*b.* Must be connected with main conductors only through double-pole cut-outs.

*c.* Must only be furnished with such resistances or regulators as are enclosed in non-combustible material, such resistances being treated as stoves.

Incandescent lamps must not be used for resistance devices.

*d.* Must be supplied with globes and protected as in the case of arc lights on high-potential circuits.

Arc lights are often run from the same circuit that supplies incandescent lamps, by connecting two in series between the two wires of the circuit. (Fig. 20.) Each lamp takes from 50 to 55 volts and the two can therefore be operated by the 110 volts pressure of the low-potential circuit. It has been remarked that with a regular series circuit the dynamo is so regulated that it maintains a constant current. Since the circuit operating incandescent lamps has a constant pressure, it is necessary to have with these arc lamps on incandescent circuits, resistances that will be cut in or cut out automatically, as the resistance of the arc lamps decreases or rises with the feeding and burning of the carbons. From remarks on page 90 it will be understood why fuses cannot be used with a constant-current circuit; but they should be used with a constant-pressure circuit, and each circuit of arc lamps on an incandescent circuit should have double-pole cut-outs with fuses, just as incandescent lamps or motors would have them.

The resistances used with arc lamps heat as any resistance does when a current is forced through it, and when the lamps get badly out of order the resistances sometimes become greatly overheated. As the rules state, it is necessary to install these resistances only in such places and in such ways as would be proper if they were small stoves.

Incandescent lamps have a definite amount of resistance in their filaments and they are made to stand considerable current for their size, so that they make convenient resistance devices. They are poor for this purpose, however, for if any of the lamps burn out, it may upset the balance and cause excessive current, as in multiple-series or series-multiple systems of lighting. (Page 102.)

### 29. Electric Gas-lighting:

Where electric gas-lighting is to be used on the same fixture with the electric light —

*a.* No part of the gas-piping or fixture shall be in electrical connection with the gas-lighting circuit.

*b.* The wires used with the fixtures must have a non-inflammable insulation, or, where concealed between the pipe and shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.

*c.* The whole installations must test free from "grounds."

*d.* The two installations must test perfectly free from connection with each other.

The lighting of gas by electricity requires only battery power of low electrical pressure, and neither the insulation on the wire nor the method of construction need be nearly so good for satisfactory operation as electric-light wiring must be. Often the gas-pipes are made to serve as one wire of the gas-lighting circuit. Connection between the gas-lighting system and the electric-light system, exposes the inferior insulation to the comparatively high pressure of the light system, and such cross-connections can cause serious damage. Accordingly where the two systems are used together on the same fixture, it is required that the standard of the gas-lighting wiring be raised virtually to that required for the lighting wiring.

**30. Sockets:**

*a.* No portion of the lamp-socket exposed to contact with outside objects must be allowed to come into electrical contact with either of the conductors.

*b.* In rooms where inflammable gases may exist, or where the atmosphere is damp, the incandescent lamp and socket should be enclosed in a vapour-tight globe.

The "socket" (Figs. 67 and 68) is the brass receptacle into which the lamp itself is fastened. One terminal of the lamp filament is attached to the brass band about the lamp base, and the other terminal of the filament is attached to the smaller brass piece coming out of the centre of the lamp base. The wires are brought into the socket and attached to terminals so arranged that when the lamp is fastened in the socket, each end of the filament is in electrical connection with one of the two wires of the circuit.

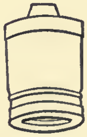

FIG. 67.—Keyless Socket.

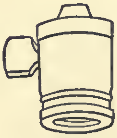

FIG. 68.—Key Socket.

The space within the socket is small and though there is room for the conductors to enter and to be attached to the socket terminals, carelessness in making the connections is apt to leave one or more of the fine wires making up the conductor projecting, so that it is free to come into contact with the socket.

There is considerable likelihood of short circuits in sockets, and though the fuses allow an excessive current to last only momentarily, if there were inflammable gas present even the very short flash would be sufficient to ignite the gas. Where the atmosphere is damp, short circuits in the sockets are apt to be numerous and though there is a probability that the fuses will take care of these, it is poor practice to depend upon safety-devices when the trouble may be prevented. "Vapour-tight globes" (Fig. 69) cover both the lamp and the socket and are an effectual protection. It is well to use them when fine dust accumulates about the socket and the attached conductors.

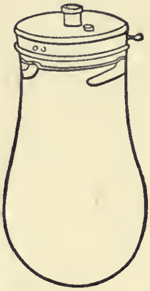

Fig. 69.—Vapour-tight Globe to cover Lamp and Socket.

**31. Flexible Cord:**

*a.* Must be made of conductors, each surrounded with a moisture-proof and a non-inflammable layer, and further insulated from each other by a mechanical separator of carbonizable material. Each of these conductors must be composed of several strands.

*b.* Must not sustain more than one light not exceeding 50 candle-power.

*c.* Must not be used except for pendants, wiring of fixtures, and portable lamps or motors.

*d.* Must not be used in show windows.

*e.* Must be protected by insulating bushings where the cord enters the socket. The ends of the cord must be taped to prevent fraying of the covering.

*f.* Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling-block or rosette, in order that the strain may be taken from the joints and binding screws.

*g.* Must be equipped with keyless sockets as far as practicable, and be controlled by wall switches.

"Flexible cord" is the name given to the species of twin wire that is formed by twisting two stranded conductors covered with insulation, about each other so that they make one cord, or piece. It is much used for pendant lamps and for portable lamps and motors, but its convenience tempts one to use it in many places for which it is not at all suitable. Since the conductors forming the two sides of the circuit are twisted close together, it takes very little abrasion or injury to the insulating covering to make a connection between these two conductors and thus form a short circuit. In addition to the usual dangers of short circuits, the silk or cotton braid covering the wires may take fire from the flash.

The rules require that each conductor of flexible cord be made up of several strands, because if a solid conductor be moved about as if it were perfectly flexible, it will sooner or later break off and cause trouble. Each conductor is to be surrounded by a non-inflammable layer to preserve the insulation in case of overheating, and there is also to be a moisture-proof layer of insulation so that accidental moistening will not cause a short circuit. The wires being also separated by a carbonizable material, if bad leakage does occur, this carbonizable separator will become a good conductor, will help the passage of a heavy current, and thus quickly cause the melting of a fuse and the stopping of further current. The two insulating layers are required so that liability of leakage between the wires may be reduced to a minimum; but when leakage does occur it is thought better to have it cause a short circuit immediately and melt the fuse.

Flexible cord is not intended to sustain weights, and the rules limit the weight that may be suspended, by allowing on one cord but one incandescent lamp; and this must not exceed in size a 50 candle-power lamp.

Flexible cord is not allowed in show windows even for pendants. There is always liability of its short-circuiting and thus causing at least a momentary blaze and perhaps a scattering of particles of molten metal. With the inflammable material usually present in show windows, these short circuits that might amount to little elsewhere may here quickly start a fire.

Where the cord enters the socket there is gradual wear of the insulation by abrasion unless the hole is bushed with an "insulating bushing" (Fig. 70). When the insulation is scraped from the ends of the conductors so that they may be connected to the terminals in the socket, the outside braid is apt to become frayed. These light ends are inflammable and would quickly catch fire from a small arc in the socket. It is accordingly required that the ends of the conductors be wound with tape to bind down the loose covering.

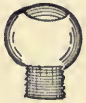
Fig. 70.—Insulating Bushing for Socket.

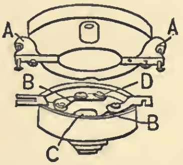

Fig. 71.—Ceiling-block or Rosette. *A*, Connections for Supply-conductors. *B*, Fuses. *C*, Hole for flexible cord, against the sides of which the knot bears. *D*, One of the Binding-screws for cord.

If a cord pull directly from the binding-screws holding it in the socket or in the ceiling-block, or "rosette" (Fig. 71), the strands are apt to pull out from under the screws and either leave too few strands to carry the current safely, or else leave loose ones to fly against the other wire of the circuit and cause an arc. The holes in the socket bushing and in the rosette are little larger than enough to allow the cord to slide through them, and by tying a knot in the cord after it has passed through the hole, the knot comes against the walls of the hole and relieves the binding screws of any strain.

Every socket that has a key for turning the light on and off, has virtually a switch within it that draws a slight arc when it operates and that is liable to get out of order. It is well to get rid of these small switches as much as possible and so reduce the chances of trouble. With "keyless sockets" (Fig. 67) the connections are permanently made, and several lights are turned on and off by one switch on the wall or in a switch closet. This switch is larger than the socket switches, and as there is not so limited a space in which the parts must be assembled, it is less likely to get out of order.

### 32. Decorative Series Lamps:

Incandescent lamps run in series circuits shall not be used for decorative purposes inside of buildings.

Decorative "series" lamps would never be operated on a pure series circuit, but would be operated on a multiple-series system, strings of lamps being connected-in between the wires of a constant-pressure circuit. (Fig. 45.) Rule 14 (*c*) prohibits any system of series-multiple or multiple-series lighting for incandescent lamps, but the rule applies only to circuits of 300 volts or over. The reasons for Rule 14 (*c*) will apply with more or less force to all series-multiple or multiple-series lighting, and the danger is considerably increased with decorative lamps because they are usually surrounded by inflammable material.

## CLASS D.

### ALTERNATING SYSTEMS. — CONVERTERS OR TRANSFORMERS.

**33. Converters:**

*a.* Must not be placed inside of any building, except the Central Station, unless by special permission of the Underwriters having jurisdiction.

*b.* Must not be placed in any but metallic or other non-combustible cases.

*c.* Must not be attached to the outside walls of buildings, unless separated therefrom by substantial insulating supports.

**34. In those Cases where it may not be possible to exclude the Converters and Primary Wires entirely from the Building, the Following Precautions must be strictly observed:**

Converters must be located at a point as near as possible to that at which the primary wires enter the building, and must be placed in a room or vault constructed of, or lined with, fire-resisting material, and used only for the purpose. They must be effectually insulated from the ground, and the room in which they are placed be practically air-tight, except that it shall be thoroughly ventilated to the out-door air, if possible through a chimney or flue.

Any explanation of alternating currents and of the laws regulating their action requires so technical a discussion that a simple statement of important facts will probably leave clearer ideas than would an attempt at an exposition.

With the alternating system the dynamo ordinarily generates a pressure of 1000 or 2000 volts. "Transformers" or "converters" are then used to change this pressure, at the place where the current is to be used, into a lower pressure of 50 or 100 volts. The pressure is high before the transformation is made and the current comparatively small; after the transformation the pressure is low and the current comparatively large. The available amount of energy is but little changed by this transformation or conversion; the current multiplied by the pressure (the number of watts) is virtually the same before as after.

This transformation is possible with alternating currents because of the principle called "induction." Suppose (Fig. 72) a coil of wire *B* to be lying near, but not touching, another coil *A* in which a current may be started either in the direction of the arrows *C*, *C*, or in the direction of the arrows *D*, *D*. Without discussing the hypotheses made to account for the phenomena, it may simply be stated that if a current be started in coil *A*, a current will also flow momentarily in coil *B* if its ends are joined; if they are not joined there will be only a momentary electrical pressure between the ends of the coil. If the current in coil *A* be now changed in direction, there will be a momentary current in coil *B* in the direction opposite to that in which it flowed in the first instance. These currents in *B* are what are called "induced currents." They last but a very short time, and if the current started in *A* be continued in the same direction, there is only a short rush of current in *B* at the starting of the current in *A*. To keep a current flowing in *B* it is consequently necessary to keep the current in *A* constantly alternating in direction. An alternating dynamo is so constructed that it will do this.

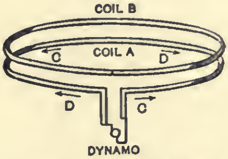

FIG. 72. — Illustrating Induced Currents.

The coil *A* which is connected with the dynamo, and in which the current first flows, is called the "primary coil," and the coil *B* in which the induced current flows is called the "secondary coil." The coils in Figure 72 have each but one turn of wire. The relation between the number of turns in the primary coil and the number of turns in the secondary coil, determines the relative electrical pressures and the relative currents in the two coils. Thus, if there are 1000 turns in the primary coil and 100 turns in the secondary, the ratio between the number of turns is 10 to 1 and the electrical pressure in the secondary coil will be one-tenth of that in the primary coil; but the current in the secondary coil will be 10 times that in the primary coil. If, for instance, the pressure at the terminals of the primary in the case supposed is 1000 volts and the current flowing is 10 ampères, then in the secondary the pressure will be 100 volts and the current will be 100 ampères. The rate of work in the two coils (the watts) will be the same; in the primary coil the number of watts will be 1000 × 10 = 10,000 and in the secondary the number of watts will be 100 × 100 = 10,000. There is simply a transformation from high-pressure and small current to low-pressure and large current. The transformer has somewhat the effect that a reducing-valve has with gas when it allows a larger flow of gas at a lower pressure. It should be remembered, however, that with the electrical transformer there is no electrical connection between the two coils; there is a space between them, and the current in the primary coil with its high-pressure is not free to pass to the secondary coil.

In practice the terminals of the primary coil are connected to the wires from the alternating dynamo, as in Figure 73, and the lamps are then connected-in between the wires leading from the terminals of the secondary coil, just as they would be on any other low-potential circuit. The two coils are surrounded by soft iron, since this greatly increases the effect and makes it possible to transform a large amount of energy in a comparatively small piece of apparatus. The two coils are compactly wound, thoroughly insulated, and placed near together, and iron plates are so formed that they will fill the space within and about the coils. The whole is then enclosed in a cast-iron case for protection against the weather and against mechanical injury.

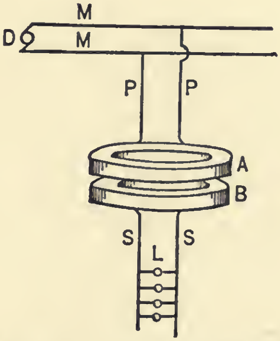

**Fig. 73.**—Illustrating Transformer Connections. *D*, Dynamo. *M*, Mains. *P*, Primary wires. *A*, Primary coil. *B*, Secondary coil. *S*, Secondary wires. *L*, Lamps.

The great advantage of the alternating system is in the saving of copper in the street conductors. If, for instance, the rate of output of a station is 100,000 watts, by using the alternating current the volts may be 1000 and the ampères 100 ($1000 \times 100 = 100{,}000$), while if the direct current (one flowing constantly in one direction) were used and the pressure were everywhere the same as at the lamps, say

100 volts, there would have to be 1000 ampères at 100 volts (1000 × 100 = 100,000). But the amount of current that is forced through a given resistance is what determines the loss. For a given loss, a smaller wire may be used for a small current at a high-pressure than for a large current at a low-pressure, although the rate of work in the two cases, as in the example cited, may be the same. (Page 34.)

When passing through a wire alternating currents under certain conditions do not follow even approximately the law that holds with direct currents. The property of induction has an important effect and on account of it sometimes a very small alternating current will flow, where with a direct current there would be a short circuit. Thus in the transformer (Fig. 73) when there are no lamps turned on and the secondary coil is consequently "open," almost no current will flow in the primary coil although it is "closed." If a few lamps be turned on so that the secondary coil is partly "closed," more current will flow in the primary, and this current will increase or diminish in almost exact proportion to the number of lamps turned on in the secondary circuit.

Transformers, or converters, become somewhat heated even under ordinary conditions, and when a short circuit occurs in the secondary circuit or when there is a defect in the transformer itself, it is possible for the temperature to become dangerously high. When a transformer "burns-out," the smudge from the burning insulation will not infrequently cause considerable smoke damage. The primary wires may become a source of danger, because they are connected to a generator of high electrical pressure so designed that it will furnish a heavy current at a constant pressure. There is some likelihood that lightning discharges will break through the insulation of the primary wires in the transformer, and if this were to occur it would be better to have the transformer out of doors and mounted so that overheating could do no damage. For the foregoing reasons the underwriters have thought it best to exclude transformers from buildings wherever possible.

### 35. Primary Conductors:

*a.* Must each be heavily insulated with a coating of moisture-proof material from the point of entrance to the transformer, and, in addition, must be so covered and protected that mechanical injury to them, or contact with them, shall be practically impossible.

*b.* Must each be furnished, if within a building, with a switch and a fusible cut-out where the wires enter the building, or where they leave the main line, on the pole or in the conduit. These switches should be enclosed in secure and fireproof boxes, preferably outside the building.

*c.* Must be kept apart at least ten inches, and at the same distance from all other conducting bodies when inside a building.

**36. Secondary Conductors:**

Must be installed according to the rules for "Low-potential Systems."

The construction of the primary circuit must be in accordance with the rules for high-potential circuits (Rules 10, 11, 12), except that Rule 35 (*c*) requires, in some places, even greater distance between wires.

All the reasons for the use of service-switches with arc-light circuits, and for the use of service-switches and main fuses with low-potential circuits, apply with even greater force to their use with primary wires in buildings, for the electrical pressure is high, and the current is not limited by the regulation of the dynamo as it is with constant-current series circuits.

## CLASS E.

### ELECTRIC RAILWAYS.

**37.** All rules pertaining to arc-light wires and stations shall apply (so far as possible) to street-railway power-stations and their conductors in connection with them.

**38. Power-stations:**

Must be equipped in each circuit as it leaves the station with an *approved* automatic "breaker," or other device that will immediately cut off the current in case the trolley-wires become grounded. This device must be mounted on a fireproof base, and in full view and reach of the attendant.

[Section *a*. Automatic circuit-breakers should be submitted for *approval* before being used.]

Electric railways are ordinarily operated at an electrical pressure of 500 volts, which the rules classify as a "high-potential"; the generators are designed to maintain this pressure constant and as they are usually of great power, a tremendous current will flow when a short circuit occurs. For these reasons the same construction is required as that specified for arc-light circuits.

An "automatic circuit-breaker" is a device for breaking connection between the generators and the outside lines. It performs the same service as a fuse, but operates instantly when there is an excessive current, while a fuse requires time to heat sufficiently to melt. The automatic breaker is operated by the current that flows out to the lines. The current passes through the wire on an electro-magnet and this magnet becomes stronger as a larger current passes. The breaker

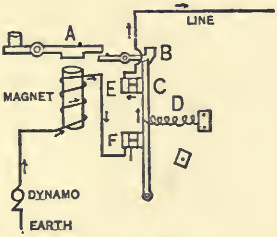

Fig. 74.—Showing Principle of Automatic Circuit-breaker. An excessive current makes the magnet attract *A*. *A* strikes *B* thus releasing *C*, which is pulled out by the spring *D*. A gap is then left in the circuit between *E* and *F*.

is so adjusted that when the magnet reaches a certain strength a piece of iron is pulled toward it, and this iron piece is so attached to a sort of trigger that a spring will be released and left free to force open a switch. Figure 74 shows the principle of an automatic breaker. In a practical form it must be so arranged that the arc formed upon opening the circuit cannot continue, and precaution must be taken that the parts to be moved will not stick. The arc that is formed has a great heating-power and the whole piece of apparatus should be mounted on a non-combustible base.

**39. Trolley-wires:**

*a.* Must be no smaller than No. 0 B. & S. copper or No. 4 B. & S. silicon bronze, and must readily stand the strain put upon them when in use.

*b.* Must be well insulated from their supports, and in case of the side or double-pole construction, the supports shall also be insulated from the poles immediately outside of the trolley-wire.

*c.* Must be capable of being disconnected at the power-house, or of being divided into sections, so that in case of fire on the railway route the current may be shut off from the particular section and not interfere with the work of the firemen. This rule also applies to *feeders.*

*d.* Must be safely protected against contact with all other conductors.

**40. Car Wiring:**

Must be always run out of reach of the passengers, and must be insulated with a waterproof insulation.

**41. Lighting and Power from Railway Wires:**

*Must not be permitted under any pretence, in the same circuit with trolley-wires with a ground return, nor shall the same dynamo be used for both purposes, except in street-railway cars, electric-car houses, and their power-stations.*

**42. Car-houses:**

Must have special cut-outs located at a proper distance outside, so that all circuits within any car-house can be cut out at one point.

**43. Ground Return Wires:**

When ground return is used it must be so arranged that no difference of potential will exist greater than 5 volts to 50 feet, or 50 volts to the mile between any two points in the earth or pipes therein.

"Feeders" are the wires that lead from the station to points where current is taken off by the different branches. If all the current required to operate a large street-railway had to be conducted from the station through the trolley-wires, either these wires would have to be of tremendous size, or else there would be great loss in forcing a large current through a small wire. If the wires were small they would greatly overheat, and the pressure would be different at different parts of the system. After a large current had been forced through the trolley-wire, there would not be so much energy left to operate the cars. Where much current is needed it is consequently the practice to use the trolley-wire only as a sort of local conductor to carry current from the ends of the feeders to the cars. (Fig. 75.).

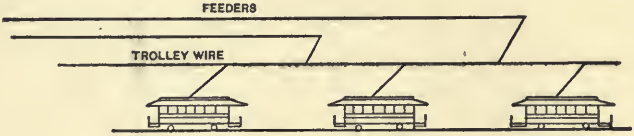

FIG. 75.—Feeders.

Street railways that use a trolley running along a wire overhead, almost invariably make the rails and the earth serve as return conductors to the station. Figure 76 shows the connections, and also indicates a stationary motor being operated from the trolley line. Quite aside from any danger, it is unsatisfactory to take current for power and light from a street-railway trolley-wire, because the electrical pressure varies when the current taken by the cars varies, and because when for any reason the circuit-breaker at the station cuts off the current from the line, the service is interrupted. It is more dangerous to operate power or lights from a trolley line than from a regular power or light circuit, for the following reasons:

One side of the circuit is always connected with the earth. With other circuits every precaution is taken to keep both wires thoroughly insulated from the earth, but with the trolley circuit one side is grounded intentionally, permanently, and as well as possible. Where both wires of a circuit are insulated from the ground, to have trouble with earth connections it is necessary to have *two* connections with the earth, one on *each wire* at the *same time.* With a trolley circuit, a bad leak or short circuit is caused by *one* connection between the one wire and the earth at *any time.* With any circuit the electrical pressure is constantly striving to force current through the insulation: there are always minute leaks. When the pressure is doubled these minute leaks double and are much more likely to become rapidly worse. With a circuit having both wires insulated, only half the total pressure is acting to break down the insulation on each wire; but where one side of the circuit is grounded, the total pressure is acting to break down the insulation on the single wire. With a grounded circuit there is likely to be more trouble from lightning because there is a connection to the earth through motors and lamps. The discharge in passing through these is apt to cause damage. It is difficult satisfactorily to operate motors from the trolley-wire when a proper fuse is used, because the fluctuations in the pressure cause the motor often to take rushes of current that will melt the fuse unless it be too large for good protection.

The foregoing are the principal reasons why light and power from trolley lines are so strongly objected to by the underwriters. Incandescent lamps operated from railway wires would be prohibited by Rule 14 (*c*) as well as by Rule 41, because with a 500 volt circuit it is necessary to connect five lamps in series and there is thus a multiple-series system.

Of course it does not make an insulated metallic circuit if two wires are run from the motor to the power-house, because the only change this makes is the connection of one wire to the earth at the dynamo instead of at the motor.

Figure 76 also illustrates the way in which the current in a trolley circuit returns to the generator. A part returns through the rails, and a part flows into the earth, and returns through buried pipes, moist earth, or any other conducting substance. This return current divides according to the conductivity of the different paths. (Page 38.) Since there is resistance it takes a part of the pressure of the dynamo to force this current from the car back to the dynamo;

thus there will be a difference of pressure between any two points in the return circuit, say between *A* and *B*. If a gas-pipe should run near the point *A* and a water-pipe should run near the point *B*, and if these two pipes should touch each other somewhere, there might be dangerous arcing due to the current finding its way back through the pipes. This is one of the reasons for Rule 43. The other and greater reason is, that if there are considerable differences of potential there is destructive action called "electrolysis" wherever the current leaves the pipe for the earth, as at *C*, Figure 76. The iron of the pipe is carried away into the earth toward the negative pole of the generator, just as in a silver-plating battery the silver is carried away from a silver plate toward the article to be plated which is attached to the negative pole of the battery.

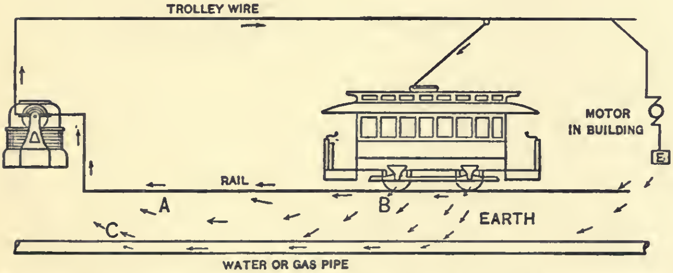

FIG. 76.—Illustrating Street-railway Circuit and Paths taken by Current.

## Class F.

### **44. Storage or Primary Batteries:**

*a.* When current for light and power is taken from primary or secondary batteries, the same general regulations must be observed as applied to similar apparatus fed from dynamo generators developing the same difference of potential.

*b.* All secondary batteries must be mounted on *approved* insulators.

[Section *b.* Insulators for mounting secondary batteries to be *approved* must be non-combustible, such as glass, or thoroughly vitrified and glazed porcelain.]

*c.* Special attention is directed to the rules (page 121) for rooms where acid fumes exist.

*d.* The use of any metal liable to corrosion must be avoided in connections of secondary batteries.

In a "primary battery" an electric current is produced by chemical action. If, for instance, a copper plate and a zinc plate are placed in a jar containing dilute sulphuric acid, chemical action produces an electrical pressure between the two plates, and if they be connected by a wire or other conductor forming a circuit, a current will flow. Batteries for operating the telegraph, call-bells, burglar-alarms, etc., are primary batteries.

One form of "secondary" or "storage battery" is made by placing lead plates and sulphuric acid in a suitable jar and then forcing a current through the lead plates and acid. When the current passes, the lead plates are chemically changed, so that if after a time the battery be disconnected from the circuit by which current is furnished, it will act like a primary battery and will produce an electric current when connected to a circuit of wires or other conductors.

Batteries may be connected so that they will give a high electrical pressure or a large current, or both, and the same precautions are then to be taken with the wiring that would be taken if the current were coming from a dynamo. With primary batteries the pressure is ordinarily very low and the current very small, so that as far as danger from fire is concerned, usually little care need be taken.

Secondary batteries are mounted on insulators because salts formed by the chemical action frequently creep over the surface of the jars, and there would be leakage of the current if the jar were not properly insulated.

Acid fumes are often produced by batteries, and care must be taken that such action will not destroy the insulation or injure apparatus.

If the metal used about secondary batteries were to corrode and waste away, the carrying capacity of the conductors would be lessened and excessive heating might occur.

**45. Miscellaneous:**

*a.* The wiring in any building must test free from grounds; *i.e.*, each main supply-line and every branch circuit shall have an insulation resistance of at least 25,000 ohms, and should have an insulation resistance between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following: —

| | | | |
|---|---|---|---|
| Up to | 10 | ampères | 4,000,000 |
| “ “ | 25 | “ | 1,600,000 |
| “ “ | 50 | “ | 800,000 |
| “ “ | 100 | “ | 300,000 |
| “ “ | 200 | “ | 160,000 |
| “ “ | 400 | “ | 80,000 |
| “ “ | 800 | “ | 22,000 |
| “ “ | 1600 | “ | 11,000 |

All cut-outs and safety-devices in place in the above.

Where lamp-sockets, receptacles, and electroliers, etc., are connected, one-half of the above will be required.

This testing can, of course, be done satisfactorily only by those familiar with electrical instruments. All insulation allows minute leakage; that is, the resistance of the insulation is never infinite. It is not safe to allow more than a certain small amount of leakage to a given length of conductor. An installation requiring only 10 ampères of current will presumably be a small one and the circuit a short one. For this reason a higher insulation resistance is required for a wiring system where the maximum normal current used is 10 ampères, than for one where it takes 1000 or 2000 ampères to supply all lamps. This insulation test is very useful as an indication, but it has principally a negative value. A low resistance indicates a fault, but a high resistance does not necessarily show perfect construction. There might be an air-space of a thousandth of an inch between a wire and a pipe, and this would prevent an indication of low resistance, but a jarring of the building might afterward bring the wire and the pipe into contact and cause a disastrous short circuit.

*b.* Ground-wires for lightning-arresters of all classes, and ground-detectors, must not be attached to gas-pipes within the building.

*c.* Where telephone, telegraph, or other wires connected with outside circuits are bunched together within any building, or where inside wires are laid in conduit or duct with electric light or power wires, the covering of such wires must be fire-resisting, or else the wires must be enclosed in an air-tight tube or duct.

*d.* All conductors connecting with telephone, district-messenger, burglar-alarm, watch-clock, electric-time, and other similar instruments, must be provided near the point of entrance to the building with some protective device which will operate to shunt the instruments in case of a dangerous rise of potential, and will open the circuit and arrest an abnormal current flow. Any conductor normally forming an innocuous circuit may become a source of fire-hazard if crossed with another conductor, through which it may become charged with a relatively high pressure.

### WIRE-PROTECTORS.

[Protectors must have a non-combustible, insulating base, and the cover be provided with a lock similar to the lock now placed on telephone apparatus or some equally secure fastening, and be installed under the following requirements: —

1. The protector to be located at the point where the wires enter the building, either immediately inside or outside of the same. If outside, the protector to be enclosed in a metallic waterproof case.

2. If the protector is placed inside of building, the wires of the circuit from the support outside to the binding-posts of the protector to be of such insulation as is approved for service wires of electric light and power, and the holes through the outer wall to be protected by bushing, the same as required for electric light and power service wires.

3. The wire from the point of entrance to the protector to be run in accordance with rules for high-potential wires; *i.e.*, free of contact with building, and supported on non-combustible insulators.

4. The ground-wire shall be insulated, not smaller than No. 16 B. & S. gauge. This ground-wire shall be kept at

least three (3) inches from all conductors, and shall never be secured by uninsulated double-pointed tacks.

5. The ground-wire shall be attached to a water-pipe, if possible; otherwise may be attached to a gas-pipe. The ground-wire shall be carried to and attached to the pipe outside of the first joint or coupling inside the foundation walls, and the connection shall be made by soldering, if possible. In the absence of other good ground, the ground shall be made by means of a metallic plate or a bunch of wires buried in a permanently moist earth.]

Ground-wires for lightning-arresters and ground-detectors are not to be attached to gas-pipes within a building, because if there were heating or arcing at the point where the wires are joined to the pipe, the gas-pipe might be burned through and the gas ignited.

Where wires are bunched together there is liability that they may become connected accidentally or on account of moisture. If there were bad leakage from one wire to another, the insulating covering might catch fire and carry it to the building. Rule 45 (*c*), consequently, requires that such wires be covered with fire-resisting material, or else that they be enclosed in an air-tight duct so that if a fire do occur it cannot have air to support combustion and cannot extend to the building.

An instrument is "shunted" when a by-path is formed round it so that the current will have a path other than that through the instrument. A high electrical pressure on telephone, burglar-alarm, or similar circuits, which do not have to be particularly well insulated, is likely to break down the insulation and cause heating at the break. Protective devices lead these high-potential currents to the ground before they get to the wiring in the building. The rules for installing protectors are given in detail in the note under 45 (*d*). Since the protector is to carry off a current forced by a relatively high pressure, all the wiring from the protector to the ground is done with the same care that would be used to install a high-potential circuit, so that there will be no leakage to the building and no burning of gas-pipes.

*e.* The following formula for soldering-fluid is suggested:—

| | |
|---|---|
| Saturated solution of zinc . . . . . . | 5 parts |
| Alcohol . . . . . . . . . . . . . | 4 parts |
| Glycerine . . . . . . . . . . . . | 1 part |

**Materials:**

The following are given as a list of NON-COMBUSTIBLE, NON-ABSORPTIVE, INSULATING materials, and are listed here for the benefit of those who might consider hard-rubber, fibre, wood, and the like, as fulfilling the above requirements. Any other substance which it is claimed should be accepted, must be forwarded for testing before being put on the market: —

1. Thoroughly vitrified and glazed porcelain.
2. Glass.
3. Slate without metal veins.
4. Pure sheet-mica.
5. Marble (filled).
6. Lava (certain kinds of).
7. Alberene stone.

On the inside of the cover of *The National Code of Rules*, as usually printed, are the following recommendations: —

The use of wire ways for rendering concealed wiring permanently accessible, is most heartily endorsed and recommended; and this method of accessible concealed construction is advised for general use.

Architects are urged, when drawing plans and specifications, to make provision for the channeling and pocketing of buildings for electric light or power wires, and in specifications for electric gas lighting to require a two-wire circuit, whether the building is to be wired for electric lighting or not, so that no part of the gas fixtures or gas piping be allowed to be used for the gas-lighting circuit.

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